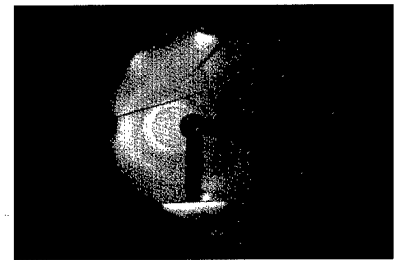


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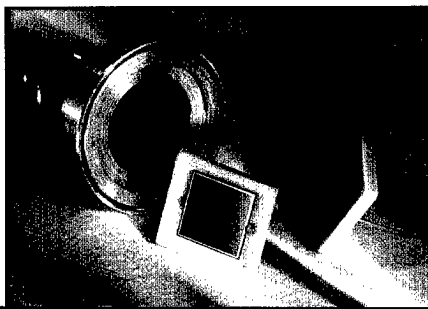
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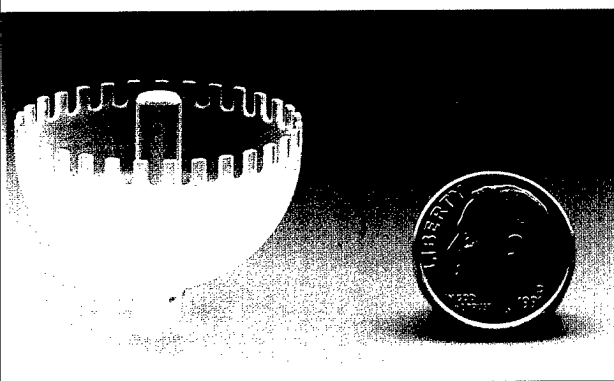


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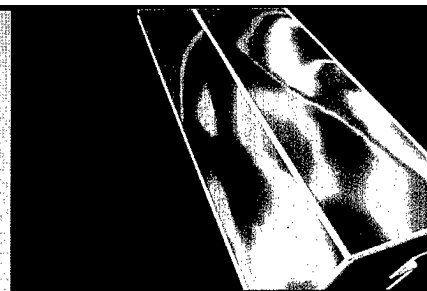
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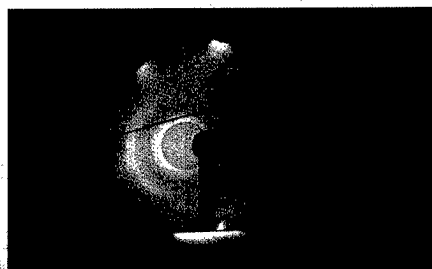
. . . because technology developed by our organization is being incorporated into commercial products on the market today—products like computer software, diamond coatings, and quality control devices. From manufacturing to medical technologies, the Ballistic Missile Defense Organization (BMDO) Technology Applications program has been actively merging defense technology with civilian ideas since 1987 to incorporate some of the most advanced research into commercial products.

This report highlights 50 BMDO-funded research projects that are being commercialized in areas such as the information infrastructure, the environment, and energy. If you are looking for more information on innovative technologies or the Technology Applications program, you can write, call, fax, or e-mail us at:

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Accession Number: 5660

Publication Date: Jan 01, 1995

Title: Technology Applications Report - 1994

Corporate Author Or Publisher: BMDO, Office of Technology Applications, The Pentagon, Washington, DC

Descriptors, Keywords: Technology Applications Report BMDO Medical Environmental Sensor Energy Information Superhighway Softwar Microelectronics Superconductor Dual-Use Transfer

Pages: 00096

Cataloged Date: Apr 13, 1995

Document Type: HC

Number of Copies In Library: 000002

Record ID: 29948

1994

Technology Applications Report

Ballistic Missile Defense Organization

Foreword

Nineteen ninety-four was a year of accomplishment for the Ballistic Missile Defense Organization (BMDO). Our Clementine satellite thrilled the nation and inspired the aerospace community with its multispectral images of the moon's surface, viewable daily on any personal computer linked to the Internet. Clementine tested 2 dozen advanced BMDO technologies in deep space, and she was launched in less than 2 years for an unfathomable \$75 million. Also, the Delta Clipper Experiment showcased BMDO's single-stage-to-orbit technology with a second successful demonstration of vertical takeoff and landing. As this publication will attest, however, BMDO has continued to exploit these and many other technological successes for their *commercial* as well as military value. The aggressive technology transfer program that we began in 1986 drives our investment strategy to consider the market and military application of our research at the start of every endeavor.

We do technology transfer for all the right reasons. First, it's the law; all Federal research and development (R&D) organizations are directed to actively try to move their R&D into other public and private applications. Second, it is good for our original funding source—the nation and the taxpayers. When BMDO-funded technologies result in commercial products, industry grows, jobs are created, and sometimes whole new businesses are born. Finally, technology transfer is good for BMDO. When we help our contractor base find additional uses for their defense-related work, we strengthen the technology base of the companies we fund. These companies can then more competitively develop innovative technologies to protect against ballistic missiles.

Our technology transfer methods have been honed to such a sharpness during the last decade that the numbers speak for themselves. BMDO-funded R&D has resulted in the following:

Roughly 170 products on the market;
At least 200 patents granted, with 150 pending;
Roughly 230 strategic alliances formed; and
At least 28 spinoff companies and subsidiaries.

This publication highlights 50 of our best success stories emerging from *real* technology transfer in the past year. Our aim is not to crow about our success, but to assure our readers that BMDO is dedicated to the concepts of dual-use defense technology and a joint military/market industrial base. This program is an integral part of our BMDO mission and will continue to promote industry growth, job creation, and national competitiveness, making the nation stronger and more economically secure in today's dynamic and challenging environment.



Dr. Dwight Duston,
Director, Science and
Technology, BMDO

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In Pursuit Of
New, Different,
And Better
Ideas At
BMDO

The Technology Applications program is just one part of a highly integrated team at the Ballistic Missile Defense Organization (BMDO). BMDO's Office of Innovative Science and Technology (IS&T) operates a complementary group of programs that not only meet BMDO's mission for a strong national defense, but also foster a strong U.S. economy. In addition to the Technology Applications program, IS&T maintains three research programs: the IS&T research program, the Small Business Innovation Research (SBIR) program, and the Small Business Technology Transfer (STTR) pilot program. The four programs work closely together, with the three research programs developing high-quality technology for defense applications and the Technology Applications program facilitating the transfer of the technology to commercial uses.

The IS&T research, SBIR, and STTR programs select and fund advanced technologies based not only on the BMDO mission, but also on commercialization potential. In fact, companies that submit proposals to request funding from these sources *must* address the potential commercial uses of their research findings.

The IS&T research program is focusing on 24 research and development areas, which provide breakthroughs in areas such as optical electronic computing, power generation, and materials. The program has roughly 400 ongoing contracts at any given time, 250 of which are with universities. R&D is conducted in five general areas which include:

- 1* Information processing and computer technology;
- 2* Sensing, discrimination, and phenomenology;
- 3* Space power and power conditioning;
- 4* Materials and structures; and
- 5* Propulsion and propellants.

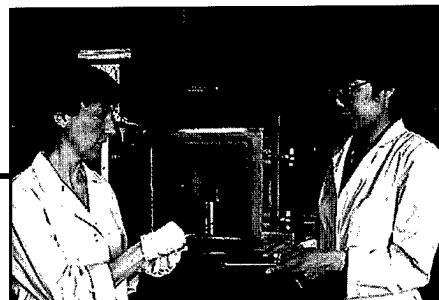
The SBIR program funds small businesses to develop far-reaching technology innovations. Over its 10 years, BMDO's SBIR program has funded more than 500 companies and 1,400 projects. BMDO funds SBIR projects in two competitive phases. In Phase I, the researcher demonstrates feasibility and develops a design concept. In Phase II, a prototype is built. A third, outside-funded phase is required to actually bring a product to market.

In an initiative that started this year called the STTR pilot program, BMDO has funded 14 Phase I projects. This program encourages cooperative joint research between small businesses and nonprofit research institutions, such as academia and government-owned, contractor-operated (GOCO) laboratories. The structure of the program copies that of the SBIR program.



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BMDO-Funded

Technology

Creates

Commercial

Opportunities

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The Ballistic Missile Defense Organization (BMDO) set out 8 years ago to provide an unbeatable defense capability for the United States and, in the process, developed innovative technology never before thought possible. Such advances have led to breakthroughs that have helped the biomedical, microelectronics, energy, and environmental industries—boosting business for many small and large U.S. companies and creating jobs. In this way, BMDO has helped the United States maintain its world leadership in both technological excellence and economic competitiveness.

Recognizing the economic value of this R&D, BMDO set up the Technology Applications program several years ago to promote the commercialization of BMDO-funded technology and to transfer it to other agencies. This proactive, multifaceted, and widely recognized program has helped move technology from the defense environment to at least 170 commercial products now on the market. It has also helped 28 new companies that have spun out from Federal laboratories, universities, and industries to manufacture products using BMDO-funded R&D. Encouraging face-to-face interaction between people in government, industry, and universities, the program is effective through several channels, including the following:

- **Outreach.** The Technology Applications program is getting the word out about innovative technologies and products through publications such as this annual *Technology Applications Report*. The program also publishes a quarterly newsletter called *The Update*, interfaces with trade and professional associations, provides referrals and networking services, and supports conferences.

- **Reviews to guide researchers in the commercialization process.** Technology Applications reviews are held throughout the year to help inventors from industry, academia, and Federal laboratories commercialize their BMDO-funded technologies. These reviews, unlike technical reviews, focus on inventors' commercialization strategies; researchers present commercialization information and receive advice from a panel of high-level experts. Each panel concentrates on a specific application area, such as microelectronics or transportation, and includes people involved in venture capital, marketing, industry, academia, and government agencies.

- **New ways to transfer technology.** Working with industry, academia, and other government agencies, the program is finding new ways to jump-start the commercialization process by formulating and validating models for technology transfer. For example, in one model involving a state economic development department, participants used a university business school to appraise the commercial potential of several new technologies. They then worked with Federal laboratory researchers to create timely commercialization strategies. In another example, case studies were conducted to develop models revolving around a technology that had numerous medical applications.

- **On-line information about innovations.** The Technology Applications Information System, or TAIS, is an on-line database that includes timely releases about BMDO-funded technologies that have been commercialized or are on the horizon. With over 1,000 abstracts, this free government-sponsored service is available to any U.S. citizen or corporation all day, every day.

Through the Technology Applications program's services, BMDO will continue to address the current needs of U.S. industry, such as those in the environmental, information infrastructure, and transportation areas—just a few of the areas where BMDO-funded technologies can make a difference—while also addressing military needs. In addition, the Technology Applications program will continue to maintain its flexibility, so that it can foster commercialization in a dynamic market economy.

The Technology
Applications program has
helped move technology
from the defense
environment to at least
170 commercial products
now on the market.

What's New

In '94?

The Technology Applications Program

What's new in '94 are new publications, enhanced on-line information, and new models for technology transfer. Using the program's services, BMDO-funded researchers and businesspeople in the commercial marketplace have made great strides in turning defense technology into products on the market today—products like greener batteries and flat-panel displays. In turn, the Technology Applications program has been working with groups outside the defense community to fully understand the ever-changing commercial needs for competing in a global economy.

The newest '94 accomplishments of the program's four main services—Outreach, Technology Applications (TA) reviews, on-line information, and demonstration projects—are highlighted below.

Outreach

The Technology Applications program's Outreach service has recently produced seven publications (in addition to this report) that are largely responsible for the recent exposure that BMDO-funded technologies have received through journals and newsletters.

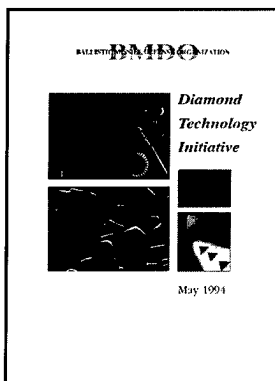
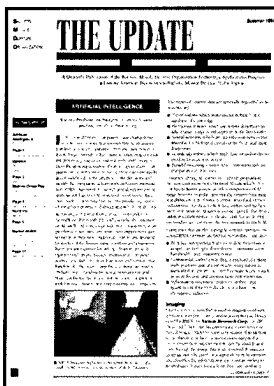
■ **Providing more information, quarterly.** The Technology Applications program has recently expanded *The Update* newsletter, previously called the *SDI High Technology Update*, to provide more—more technologies, more companies, more pages—more concisely. It also features a Market Watch column, which discusses business concerns related to technology transfer such as university incubators and partnerships.

Circulated to roughly 5,000 executives, researchers, marketers, media contacts, and government officials, *The Update* has received a wide and positive response, stimulating collaborations, product purchases, joint ventures, and publicity. As of August 1994, 14 issues have been published, which include 150 stories on roughly 250 technologies.

The last two issues (Winter and Spring 1994) have resulted in over 1,300 requests for more information on specific technologies and articles. Recent topics that have received the greatest interest were the Diamond Technology Initiative, holographic photovoltaics, a heat-storing material, and technologies for oil drilling.

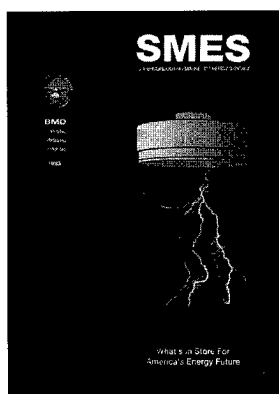
Earlier issues of *The Update* have proven to be profitable for companies highlighted in articles. For example, an article on the Rotolok® high-precision rotary drive that appeared in the Spring 1993 issue of the newsletter provided the company with exposure that led to greatly increased product sales.

■ **The Diamond Technology Initiative.** The BMDO Diamond Technology Initiative is a research program that is developing diamond coating technology for missile defense. Already it has contributed to 3 commercial products, fostered 22 collaborative ventures that may introduce future products, and generated at least 31 patents. Most of the commercial progress is in small-volume markets, such as x-ray windows, custom coatings, and certain machine-tool applications. Larger markets, such as flat-panel displays that use diamond cold cathodes and microelectronic heat spreaders, are just now emerging.



The big payoff—the one that the BMDO Diamond Technology Initiative set its sights on from the beginning—will not come until diamond semiconductors can be produced with cost-performance benefits that exceed those of devices made from other materials. While that day has not yet come, the BMDO Diamond Technology Initiative continues a broad-based research program in diamond thin-film coatings to produce large-area, single-crystal diamond coatings at a cost competitive with other electronics-grade materials.

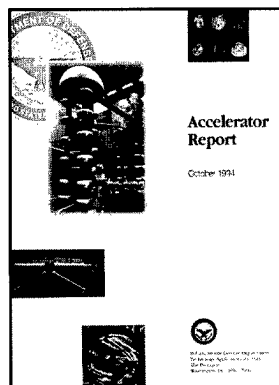
The Technology Applications program released a 56-page report titled *Diamond Technology Initiative* in May 1994. This report surveys diamond research and describes 25 ongoing and recently completed projects funded through BMDO's Diamond Technology Initiative. The report has been published to stimulate industry interest so that companies will incorporate existing developments in diamond coatings into commercial products and collaborate to develop future diamond-coated products.



■ **Innovative energy storage techniques.** Superconducting magnetic energy storage (SMES) is an innovative technology that may offer utilities, industry, and transportation a highly efficient and reliable alternative to traditional methods for storing energy. Large-scale SMES was partially funded by BMDO through the Engineering Test Model.

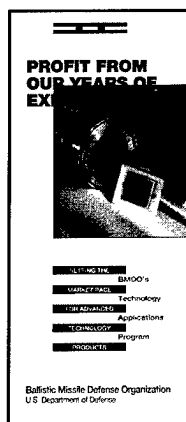
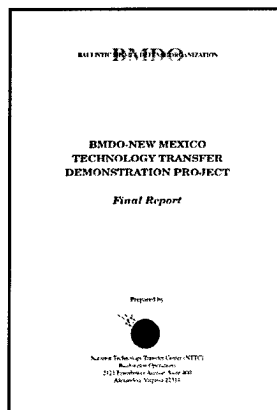
In an effort to transfer SMES technology funded in part by BMDO, the Technology Applications program has recently published a 12-page brochure titled *What's in Store for America's Energy Future*. This color publication describes potential applications of SMES in lay terms. Information in the brochure is based on a study conducted through a BMDO-funded demonstration project that analyzed SMES for its commercial potential. A 57-page technical report is also available.

■ **Medical and environmental uses for accelerators.** The reduced size, weight, and cost of particle accelerators have allowed them to be used for commercial applications. Accelerators have started—or are ready to start—treating cancer, producing isotopes for medical imaging, sterilizing medical products, and cleaning up the environment. BMDO, as part of its mission, has led much of this progress.



The Technology Applications program has published the 23-page Accelerator Report that describes BMDO-funded accelerator technologies and their potential applications in the commercial marketplace. The goal of this report is not only to disseminate information, but also to stimulate discussion with a broader range of potential users in industry, universities, and other Federal agencies. This publication has been produced partly in response to a BMDO-funded demonstration project on accelerator technology.

■ **Assessing technology and instilling value.** One of the most difficult tasks facing technology developers and technology transfer officials is how to assess a technology once the invention has been disclosed. This critical time in the commercialization process can have a far-reaching impact on a technology's value in the marketplace. For example, during this period, the inventor must decide how to manage intellectual property or publication of invention results. BMDO led a technology transfer demonstration program to address these issues and to expedite decision making about intellectual property and technology value.



The BMDO–New Mexico technology transfer demonstration project was a collaborative effort among Federal, State (New Mexico), university, and private organizations to identify and evaluate the commercial potential of several technologies and to recommend commercialization strategies. In this project, the School of Business at the University of New Mexico conducted a market analysis on 12 BMDO-funded technologies with strong commercial potential. On the basis of this study, three commercially viable technologies with the strongest potential were selected, including a noninvasive glucose monitor, a vacuum dryer, and a photocathode manufacturing technique. This joint effort was sponsored by BMDO, the Technology Enterprise Division of the New Mexico Economic Development Department, Los Alamos National Laboratory, Sandia National Laboratories, and the Air Force Phillips Laboratory.

How did this model work? The Technology Applications program has just released a report on this important demonstration program, called *BMDO-New Mexico Technology Transfer Demonstration Project*, which may help other state governments and Federal laboratories commercialize their technologies.

■ **Other technology-focused reports.** With plans to produce similar technology-focused reports, the Technology Applications outreach team is preparing one on battery technologies. The report will also include related technologies such as capacitors, fuel cells, and flywheels funded by BMDO.

■ **Program profile.** The Technology Applications program has also recently produced a new color brochure on its own program activities. Widely distributed and available in bulk packages of 50 or fewer, this brochure highlights program elements that may be useful in helping both researchers and industry commercialize BMDO-funded technology.

■ **Press coverage.** The Technology Applications program acknowledges that outside press coverage can help considerably in transferring technology both to the commercial marketplace and to other agencies. This year, the program has documented over 60 articles about BMDO technology commercialization that appeared in national and local publications as a result of Outreach efforts. These articles generated over 400 requests for additional information on the Technology Applications program or specific technologies. Representative publications in which articles appeared include *The Wall Street Journal*, *Business Week*, *Aviation Week & Space Technology*, *Design News*, *Newsday*, *National Defense*, and *The Washington Post*.

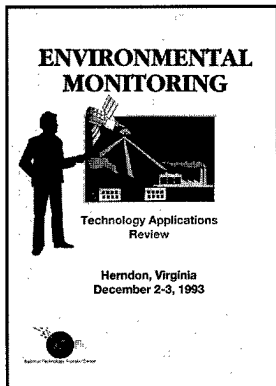
■ **Professional societies and trade associations.** The Technology Applications program also works with more than 50 professional societies and trade associations to maintain an industry focus. Some of the associations with which it works closely are the American Association of Engineering Societies, the Industrial Research Institute, the National Coalition for Advanced Manufacturing, and the Telecommunications Industry Association.

Publication requests can be made by using the reader response card inside this report and mailing it back to the National Technology Transfer Center.



Reviewing Commercialization Strategies

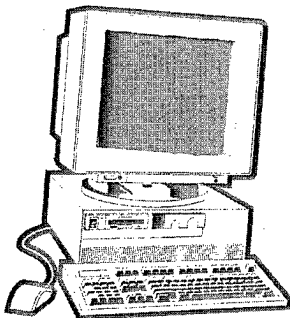
Using a forum approach to help commercialize BMDO technology, the Technology Applications program has held 33 TA Reviews. Over the years, 192 inventors from industry and nonprofit organizations, 40 researchers from universities, and 62 researchers from government organizations have presented their commercialization strategies at these reviews.



The program currently concentrates on industry and national needs rather than technology areas. For example, subjects for this year's focus include the information superhighway, the environment, and transportation. The program has been highly successful in organizing constructive review teams in these areas and has been able to effectively communicate the technology requirements in the specific application areas to the defense community. In addition, through TA Reviews, the program has made a concerted effort to help commercialize BMDO-funded technologies developed at other agency laboratories, including the Air Force Phillips Laboratory.

TA Reviews have been instrumental to the commercial success of dozens of small and large companies. A recent example of TA Review success is a presentation from Northeast Photosciences, (Hollis, NH) a company funded by BMDO's Small Business Innovation Research (SBIR) program that is developing a holographic photovoltaic device (see page 44). As a result of the TA Review, the company president was referred to several contacts in industry, venture capital, and government. These contacts are now working with Northeast Photosciences to transfer the technology into areas such as utility-scale solar-electric power generation—an application that not only addresses a potential commercial avenue for the company, but also addresses the environmental need for cleaner power generation nationwide.

Joint TA Reviews are also being held with the National Aeronautics and Space Administration (NASA). The first joint review focused on intelligent software. Three BMDO-funded technologies and four NASA-funded technologies were presented. One technology funded by both BMDO and NASA was also presented. This joint review process was initiated to best leverage the review panel in the focus area. Because of the review's success, two additional joint reviews are being held in the areas of transportation and environmental technologies. The Technology Applications program is interested in working with other agencies as well.



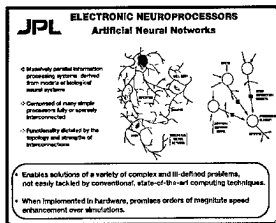
Innovations for American Businesses—On-Line

The Technology Applications Information System (TAIS) contains hundreds of innovation highlights that describe BMDO-funded technologies that are either being commercialized or are on the horizon. The database system has recently been enhanced to suit those looking for new technologies for their specific needs. Abstracts have been expanded to include important commercialization information in lay terms. The TAIS also includes research funded through the BMDO SBIR and STTR programs.

The Technology Applications program has also expanded access to the TAIS, enabling *any* American citizen to use the service with three 30-minute access blocks every day. New users can register on-line the first time they log on and will receive a database password within a few days. The new system offers full text search capabilities and can handle transmission at up to 9,600 bits per second.

Innovative New Models To Commercialize Technology

The Technology Applications program has begun developing and evaluating several new models for transferring technology, as described below.



■ **Advanced neural networks for commercial uses.** The Technology Applications program is also sponsoring the advanced neural network demonstration project at NASA's Jet Propulsion Laboratory (JPL). This project will formulate a model to move neural network technology developed by JPL to commercial uses. Neural networks are massively parallel processing systems, derived from models of biological neural systems. They can solve complex and ill-defined problems not easily tackled by other advanced computing techniques. They have numerous applications in the education, environmental, and industrial sectors.

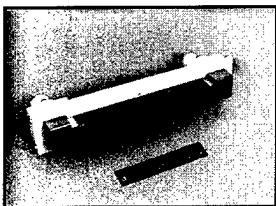
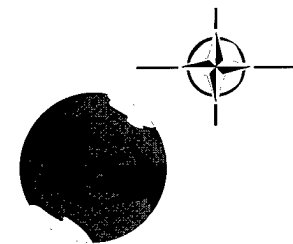
The goal of the program is to choose the best market area for JPL's technology, define a marketable product, and then transfer the neural network product into that market area. This demonstration program requires cooperation among JPL, the Technology Applications program, and outside partners in the commercial marketplace.

■ **International technology transfer.** The Technology Applications program is also cosponsoring a North Atlantic Treaty Organization (NATO) Advanced Study Institute symposium on defense conversion strategies. The BMDO Technology Applications program will be one model used to illustrate successful examples of the transition of defense technology to the commercial market. NATO's symposium will take place in July 1995 in Pitlochry, Scotland.

■ **Commercialization of technology at Defense laboratories.** BMDO does not have its own laboratory; it funds technology development at Defense and national laboratories that have the most expertise in a given technology area. In this light, the Technology Applications program is currently cooperating with the Office of Technology Transition, under the Director, Defense Research and Engineering (DDR&E) in the Office of the Secretary of Defense (OSD) by hosting a meeting between officials at both the laboratory and headquarters levels. This meeting will facilitate a new program that funds partnerships between Defense laboratories and selected industrial partners to transfer laboratory technology to the commercial marketplace.

■ **BMDO-funded technology for medical uses.** The Medical Free Electron Laser (MFEL) program was established in 1985 and funded through BMDO to develop applications of the free electron laser for clinical medicine and related materials science. The program involved seven medical centers, three materials science centers, three free electron laser facilities, and many individual researchers at other institutions. The Technology Applications program funded a demonstration project to assess the MFEL program as a model for technology transfer. The demonstration project evaluated the productivity of the program as well as yardsticks for measuring it.

The following sections of this report highlight the top 50 BMDO-funded commercial success stories for 1994. Many of these products that companies, universities, and laboratories are developing are currently on the market, three of the companies have recently gone public, and at least two of the companies have spun out from large companies and laboratories.



Beckman Laser Institute,
page 18

BMDO

Technology

Makes

Commercial

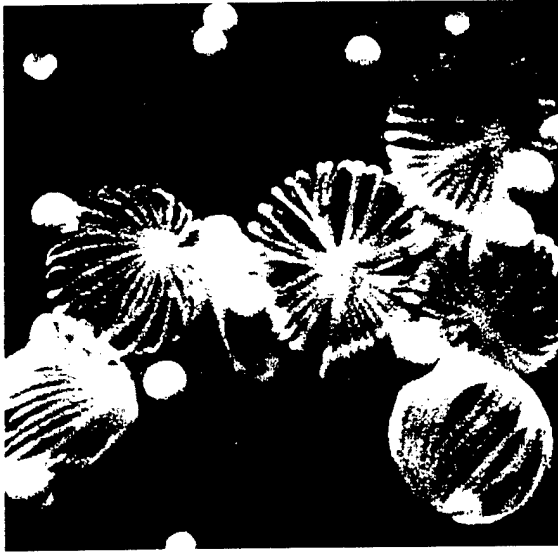
Sense

Many corporations have incorporated Ballistic Missile Defense Organization (BMDO)-funded technology—which includes some of the most advanced innovations in the world—into their product lines, giving them the competitive edge in what is now an extremely dynamic international marketplace.

- At least 28 companies have spun off from Federal laboratories, private companies, or universities to commercialize BMDO-funded technology.
- Roughly 170 new commercial products have resulted from BMDO-funded technologies.
- Eight companies funded by the BMDO Small Business Innovation Research program have gone public, with commercial products available in the marketplace.
- Over 230 ventures have been formed using BMDO-funded technology as a basis.
- At least 200 patents have resulted from BMDO funding, with 150 pending.
- At least 15 cooperative research and development agreements have been established in which BMDO has funded technology at the Federal laboratory prior to the agreement.

This report was written and produced for the Ballistic Missile Defense Organization by the National Technology Transfer Center.

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*Clark-MXR,
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Medical Technologies

The United States produces roughly half of the world's medical technology, employing about 279,000 people in the nation, and exporting about \$9.6 billion in products. In 1993, the United States produced \$41.7 billion in medical devices and diagnostic products; production is projected to grow to \$48.6 billion by 1995.

This industry relies heavily on the innovative breakthroughs provided by the 11,000 companies that contribute to its products—most of which are small businesses. In fact, according to the Food and Drug Administration, about 70 percent of the companies in the medical technology industry employ fewer than 50 workers, and 64 percent employ fewer than 20. In addition to improving the quality of life for millions of people, innovative technologies that these businesses provide may actually lower medical costs by detecting diseases earlier or offering alternatives to traditional treatments and extended hospital stays.

BMDO's highly advanced developments in areas such as lasers, accelerators, and optics are now contributing to innovative breakthroughs in the medical community. With R&D in new medical techniques for mammography, cancer therapy and detection, ophthalmology, and improved surgical devices, researchers are developing new life-saving technologies and quality-of-life improvements stemming from ballistic missile defense.

Industry figures provided by the Health Industry Manufacturers Association.

Laser R&D To Improve Cancer Therapy Technique

Beckman Laser Institute and Lawrence Livermore National Laboratory are teaming to fight cancer with laser technology developed under BMDO.

From treating cancer and infertility to removing birthmarks, Beckman Laser Institute (Irvine, CA) and Lawrence Livermore National Laboratory, or LLNL, (Livermore, CA) are on a 2-year, \$1.3 million mission to make cheaper, smaller, and more efficient medical systems.

Using BMDO-funded research in micro-optical lenses and microchannel coolers, these two groups have teamed in a cooperative research and development agreement (CRADA) to develop three prototype laser systems.

The first system is to further develop a cancer treatment called photodynamic therapy. In this treatment, chemical photosensitizers are introduced into the cancerous area. Lasers tuned to specific wavelengths illuminate the area and cause the photosensitizers to react with oxygen in the tumors, converting the oxygen to an active form that kills the cancer cells.

Another system, still in the research stage, will be used in fertility treatment for both humans and animals. The lasers will drill tiny holes in

the surface of eggs to help sperm penetrate the egg casing.

The research team is developing a third system to improve on existing techniques for removing port wine stains (purplish birthmarks) from infants and young children.

The lasers heat and destroy the abnormal vessels in the skin below the surface, removing the discoloration after several treatments. LLNL's advances will allow physicians to adjust the duration of the laser's pulse, tailoring it to the patient.

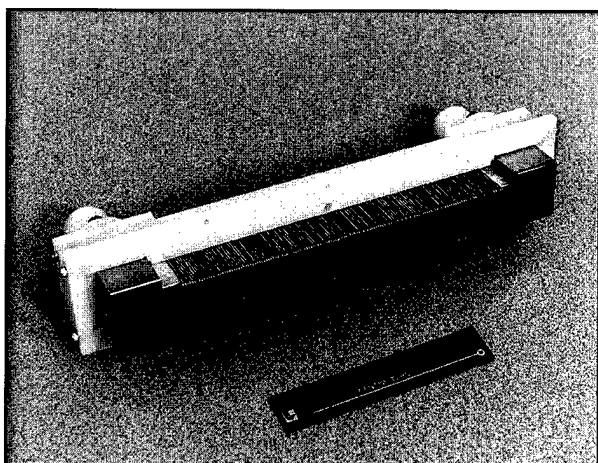
The BMDO-funded research was through the Medical Free Electron Laser (MFEL) program, which was an effort to transfer free electron laser research for ballistic missile defense to

the medical community. Since 1985, BMDO has provided over \$50 million to universities and medical research institutions. Since 1991, funding for the program has continued through the Office of the Secretary of Defense.

ABOUT THE TECHNOLOGY

High-power laser diodes and diode-pumped microlasers have advantages over flash-lamp-pumped solid-state lasers, but laser diodes generally have greater beam divergence, limiting the degree of focus that can be achieved. LLNL has developed a cylindrical microlens for divergence correction. The microlens focuses the radiation from each diode bar, enabling the output radiation from the diode stacks to be efficiently delivered to the end of a rod laser. The laser then operates more efficiently and can achieve higher power levels than it could without the lens. A fiber-optic pulling technique, in which the material is kept cool and viscous to retain the shape of the preform, can be used to manufacture thousands of the microlenses quickly and affordably.

For high-power semiconductor lasers, heat extraction from the laser-active medium also becomes important. The silicon microchannel cooler allows laser-diode packages to efficiently shed the intense heat generated at the laser-diode array with only a slight rise in temperature. These coolers are microscopic water channels buried beneath the silicon surface of the package, created with standard photolithographic techniques.



■ Pictured above is a 2-dimensional diode array for pumping a Nd:YAG (neodymium-doped yttrium-aluminum garnet) slab laser.

Technique Shows Promising Results For Cancer Detection

Using this optical spectroscopy technique, researchers have achieved roughly 96-percent accuracy in detecting malignancies in breast tissue.

Doctors know that early detection of cancer can mean a better chance for cure. Working on a technique sometimes called optical biopsy, researchers at the City College of New York's Institute for Ultrafast Spectroscopy and Lasers, or IUSL, (New York, NY) are finding ways to use light instead of scalpels to detect cancer more precisely.

Gaining a highly interested audience from the medical community, these researchers have achieved 96-percent accuracy in detecting cancerous breast tissue—not to mention 87-percent accuracy in tests on gynecological tissue. They have begun commercializing their new life-saving technique through the Mediscience Technology Corporation, or MTC (Cherry Hill, NY).

In optical spectroscopy, technicians illuminate the site being tested with laser or lamp light and then measure the resulting fluorescence from the sample. Spectroscopy identifies certain characteristics, such as chemical composition, atomic energy levels, or molecular geometry. The research was originally funded through the



■ In optical spectroscopy, researchers can use laser or lamp light to identify certain characteristics, such as chemical composition or atomic energy levels. Researchers at IUSL (pictured above) have been using this technique for optical mammography.

Free Electron Laser (MFEL) program, which was designed to promote medical applications of BMDO's laser technology.

MTC has provided optical spectroscopy devices for other groups to detect cancer and other abnormalities. For example, working with Stimson Schantz, M.D., of the Memorial Sloan-Kettering Cancer Center (New York, NY), MTC is researching optical spectroscopy to detect oral malignancies and abnormalities. Schantz hypothesizes that IUSL's technique will lead to earlier detection of both genetic and cellular damage in the mouth. When

caught early, the problem can potentially be treated with preventative measures such as vitamins or behavior alteration.

In addition, MTC has provided optical spectroscopy technology to Mark Bessler M.D. from Columbia Presbyterian's Department of Surgery (New York, NY) to detect stomach, esophagus, and colon cancer. Bessler has been using surgical specimens to test the technique with promising results; MTC plans to build a small endoscope for future clinical testing—possibly sometime next year.

But laser- or light-induced fluorescence can also be used for other medical applications. For example, MTC provided technology to James Slater, M.D., and Mehmet Oz, M.D., cardiac surgeons with Columbia Presbyterian who are applying optical spectroscopy to observe metabolism and blood flow noninvasively. The tool would be useful for monitoring the heart during surgery. Their method is currently undergoing intensive testing on both rats and large animals.

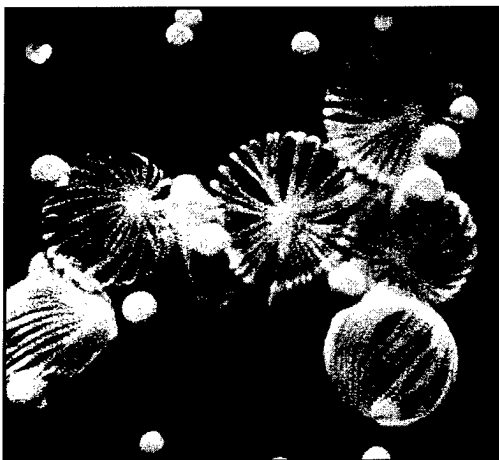
Other applications of optical spectroscopy could include testing chemical solutions used to preserve organs for transplant, examining potentially cancerous skin lesions, evaluating wounds, and monitoring and improving the laser welding of biological tissue.

ABOUT THE TECHNOLOGY

In optical spectroscopy, researchers illuminate a test sample with laser or lamp light and then measure the resulting fluorescence to identify certain characteristics, such as chemical composition, atomic energy levels, or molecular geometry. Research has indicated that the ratio of fluorescence intensities at 340 and 440 nanometers differs consistently between malignant and benign tissue. It should be noted that IUSL's technique can only differentiate between cancerous and noncancerous tissue, not between different types of cancers.

Smaller Laser Device Fits Into Medical Market

In addition to Clark-MXR's new alignment system, called PointMaster™, BMDO funding has contributed to the company's research in innovative surgical tools and practices.



■ Demonstrating two-photon confocal microscopy, this picture shows a 3-dimensional image of stained spathophyllum pollen next to 4.7-micron beads. It was obtained with a large unit, but the technique's wide use depends heavily on compact sources, such as those developed by Clark-MXR.

From measuring molecular motion to detecting tumors, Clark-MXR (Dexter, MI) has made a femtosecond laser device small enough for many medical uses. Such devices have been limited to the laboratory because of their bulky design, but big ideas in BMDO research have made these sources small enough to be used by the medical community.

When used for microsurgery, the shorter pulse duration of Clark-MXR's optical sources can provide—in real time—a clean cut and a simple way to measure the depth of an incision. The company is working with the University of Michigan's Kellogg Eye Center to evaluate the quality of the laser-produced cut. Clark-MXR is also collaborating with Picometrix, Inc., (Ann Arbor, MI) (another BMDO-funded company) to use femtosecond laser pulses and ultrafast detectors for measuring incision depth. This research is through a National Aeronautics and Space Administration SBIR grant.

Clark-MXR's laser device can also be used with ultrafast detectors for imaging through the human body to detect subcutaneous tumors or fluid in

the lungs. And it can be used to measure the motion and concentration of molecules in cells, in a technique called two-photon confocal microscopy. Such measurements reveal information about the activity of specific macromolecules—for example, those that govern serum cholesterol. Clark-MXR's compact laser sources could produce ultraclear images that are well suited for the medical market.

As a byproduct of this research, the company is also selling a computer-controlled alignment system called PointMaster™ that automatically maintains alignment of optical sources. When used with the femtosecond laser, the device can benefit medical applications as described above and can also make a good fit in areas outside the medical arena. For example, the

company's devices can be used together for robotic vision, semiconductor testing, photoconductive switches, and general research.

BMDO originally funded this research at Medox Research, Inc., (MXR) for ballistic missile defense purposes. MXR, a small business evolving from the Ultrafast Optical Science Laboratory at the University of Michigan, later merged with Clark Instrumentation.

ABOUT THE TECHNOLOGY

Ultrafast laser devices are complex, typically requiring large, heavy, power-inefficient argon-ion, Nd:YAG (neodymium doped yttrium-aluminum garnet), or similar lasers as primary pump sources. Clark-MXR, on the other hand, is using laser diodes—small and relatively inexpensive lasers used in laser printers—to pump femtosecond optical sources. Clark-MXR's latest pump source is 300 times smaller and 60 times lighter than traditional ultrafast optical sources. To achieve the smaller and less complex design, they use a process called self-modelocking. The company has demonstrated 20-femtosecond LiSAF lasers and is currently generating femtosecond pulses using diode pumping over most of the 750- to 1,300-nanometer wavelength range.

Traditional femtosecond optical sources also require skilled operators of machines to generate short pulses because, when left alone, femtosecond optical sources drift out of physical alignment and stop producing short pulses. As a byproduct of their research on compact femtosecond optical sources, Clark-MXR developed a computer-controlled alignment system called PointMaster™ that can correct lateral displacement of up to 500 microns and angular displacements of up to 1 milliradian.

Technique Gives Patients A Head Start In Cancer Therapy

Fischer Imaging and Lawrence Livermore National Laboratory are developing a digital mammography system to automatically recognize and flag the early danger signs of breast cancer.

Current mammography techniques, although valuable tools for detecting breast cancer, are nowhere near perfect. With these techniques, the early signs of cancer are difficult to see and therefore easily missed by doctors. In fact, about 60 percent of patients with breast cancer had previous mammograms in which the early warning signs of malignancy were present but were overlooked. BMDO-funded development in image digitization and algorithms may help solve this problem.

Through a cooperative research and development agreement (CRADA) between Fischer Imaging (Denver, CO) and Lawrence Livermore National Laboratory, or LLNL, (Livermore, CA) a team of researchers is using BMDO-funded technology to build a complete digital mammography system. With this system, doctors could more easily detect cancer at

missed by the human eye, microcalcifications appear as tiny specks scattered across the breast image. The team's system would recognize and highlight these abnormalities for the doctor reading the mammogram.

On a similar project, Fischer Imaging has recently signed a letter of intent with another BMDO-funded company, SI Diamond Technology, Inc., (Houston, TX) to develop flat-panel displays using diamond cold cathodes for its digital mammography system. LLNL is also interested in finding partners for a project to develop a comprehensive computer system that can recognize all the known warning signs of breast cancer within a mammogram. (The system currently being used in the CRADA has more limited capabilities.)

ABOUT THE TECHNOLOGY

BMDO originally funded research at LLNL to digitize film images of synthetic materials with properties similar to those of tissue in order to detect defects in defense-related materials. Noting that film images of human tissue could also be digitized, researchers began applying the defense research to digital mammography.

In the digital mammography process, technicians digitize mammogram films. While image digitizers are now commonplace in some market areas (every fax machine has one), the stringent requirements of digital mammography are inhibiting their expansion into that area. A research instrument funded by BMDO, however, has high enough spatial resolution and data precision to provide breakthroughs in mammography.



■ A BMDO-funded research instrument has the spatial resolution and data precision to make digital mammography possible. Pictured above, an LLNL engineer examines a computer digital mammogram display.

its earliest stages and subsequently begin early treatment. And since the system eliminates x-ray films, it could lead to more efficient record keeping, more easily transferred records, and a better ability to consult on difficult cases.

The industry-laboratory partnership is using computers to clarify and screen mammograms so that subtle indications of cancer, such as microcalcifications, are not overlooked. Often

BMDO R&D May Help Make Clearer Images For Ophthalmologists

Industrial Sensors and Actuators is developing a low-cost noninvasive test that can detect glaucoma much earlier than current tests.

Industrial Sensors and Actuators, or IS&A, (San Leandro, CA) is developing a noninvasive test that diagnoses glaucoma long before today's conventional tests can sense it, using technology developed under a BMDO SBIR contract.

With \$2 million in contingent matching funds from outside commercial sources, IS&A's defense developments in adaptive optics are being looked at by users in ophthalmology. IS&A's research and development for medical applications is based on the low-cost deformable mirror, sometimes called a rubber mirror. This mirror can compensate for distortions in optical systems in real time. The company's fabrication technique results in a device that costs one-tenth as much as those currently on the market.

Cheaper manufacturing is expected to lead to a wealth of other applications as well. For example, deformable mirrors can improve the images of ground-based telescopes used for astronomy. They can also improve the resolution of photolithography, a commonly used printing process.

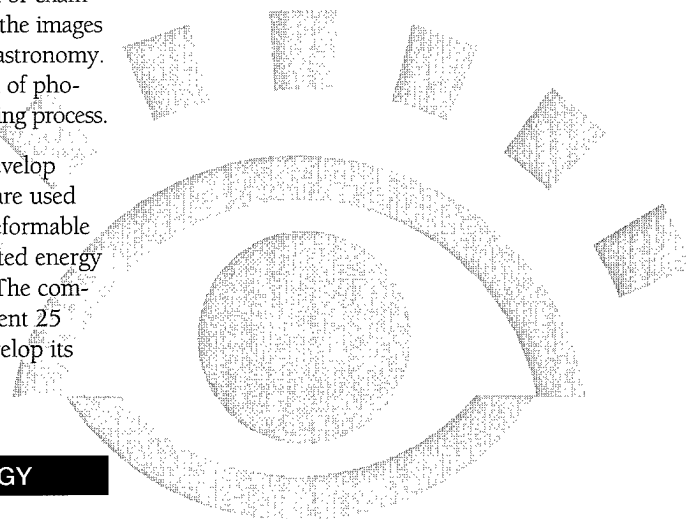
BMDO originally funded IS&A to develop piezoelectric actuator arrays, which are used for the deformable mirrors. These deformable mirrors could then be used for directed energy weapons and space object imaging. The company plans to scale up from the current 25 actuators to 100 in a system and develop its product for ophthalmology.

fabrication of such multilayer systems was still too expensive for broad commercial applications. IS&A has developed a technique for fabricating multiple actuators as a sheet, substantially reducing the cost and improving the reliability of the resulting device.

ABOUT THE TECHNOLOGY

IS&A's mirror is composed of an array of piezoelectric actuators bonded to a reflective glass sheet. Each actuator is driven with its own voltage, changing its length when electricity is applied. The mirror can therefore be deformed as needed to remove aberrations in an optical system. For example, the blurring of images obtained through atmospheric turbulence can be removed using this technique.

Originally, these mirrors required high voltages and were exceptionally expensive. Researchers found that they could reduce voltages by placing the actuators in multiple layers, but the





*Amber,
page 26*

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Environmental Technologies

From greener manufacturing processes to devices that can clean up toxic waste, technologies are needed to address a wide spectrum of environmental problems. Demand for monitoring and assessment, pollution prevention and control, and remediation and restoration represents a dynamic marketplace with a wide-open playing field. In fact, the current \$200 to \$300 billion world market for such technologies¹ may approach \$600 billion in 5 years. Holding just under half of the global environmental industry market, the United States is the world leader in this arena, with an estimated 45,000 to 60,000 companies involved in environmental technology. National activity is expected to grow as well, since the environmental technologies arena is a market domestically driven by an ever-increasing number of regulations such as the Clean Air Act and the Clean Water Act.

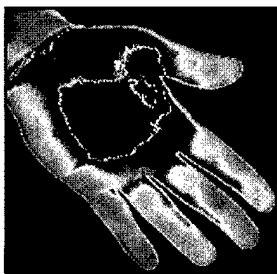
BMDO has funded technology for ballistic missile defense that can also provide the environmental industry with innovative solutions to help the United States maintain a strong presence in this ever-growing world market. For example, BMDO-funded sensor technology may provide the real-time sensors that industry is increasingly demanding, and power technologies may soon provide cleaner manufacturing alternatives. The Technology Applications program is assisting BMDO-funded companies and laboratories with technologies that are either being marketed for or have strong potential in environmental applications. In fact, some BMDO-funded companies already have products for environmental applications on the market.

¹Market figures are based on information obtained from the Interagency Environmental Technologies Exports Working Group's *Environmental Technologies Exports: Strategic Framework for U.S. Leadership 1993*.

Amber Offers A Portable Solution With High Resolution

Amber is marketing Radiance 1, a compact, high-resolution infrared camera that can be used for environmental monitoring, surveillance, and materials analysis.

■ Applications of Amber's Radiance 1 infrared camera include environmental monitoring, medical diagnostics, and surveillance.



From smoke stack emissions to wildlife monitoring, Amber's (Goleta, CA) Radiance 1 infrared (IR) camera can give industries and environmentalists a clear picture of what is going on in today's changing ecology. With the best pixel resolution in the mid-IR wavelength range, this easy-to-use portable monitor can rapidly respond to our nation's ever-growing green standards.

Radiance 1's advantages also make it ideal for other uses. For example, the compact camera can be used as a medical diagnostic tool or as a security monitor. It also can serve as a non-destructive way to analyze materials.

Amber, a division of Raytheon, is currently selling customized systems for \$80,000 to high-end users such as military and intelligence organizations for airborne and ground-based surveillance operations. Mass production is expected to drive down the cost, making these cameras available for the more cost-conscious commercial users; however, the system is currently price competitive with—and has a higher performance than—cameras being used for surveillance operations.

Amber has also introduced two related software systems, Amber-View™ and Pro-View™, to process images. And as a second-generation product, Amber is improving the camera's resolution so that it compares to that of current computer graphics video products.

Amber developed indium antimonide (InSb) and mercury cadmium telluride focal plane array sensors for BMDO's Advanced Large-Area IR Transducer (ALIRT) Program. ALIRT was designed to improve IR sensor technology for intercontinental missile surveillance and tracking.

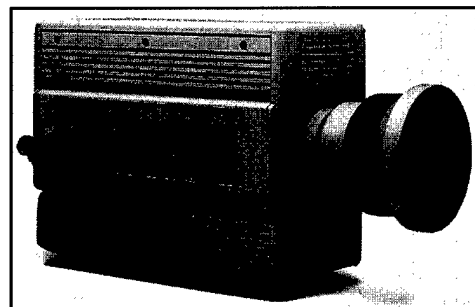


ABOUT THE TECHNOLOGY

Amber has integrated InSb array sensors, advanced compact cryocoolers, and image control and processing software into its portable IR camera and image processor. The heart of the digital IR camera is the InSb focal plane array sensor. InSb, the detector of choice for midwave IR signals, provides optimum signal-to-noise detection at cryogenic temperatures. Current InSb arrays are produced in 256 by 256 pixel format, with 512 by 512 units in development.

To provide cooling, Amber's system uses advanced portable cryocoolers that require no liquid nitrogen dewar and are suitable for unattended operation. In terms of reliability and cost of operation, these cryocoolers compare extremely well to more conventional sensor cooling systems.

Amber has also integrated detection and signal-processing electronics (such as a fast digital frame grabber), digital signal-processing algorithms (such as fast Fourier transform processing), and display software into easy-to-operate image acquisition and manipulation systems. The newest system operates on a 486-PC and takes advantage of the most recent fast video display bus architecture.



■ Amber's Radiance 1 infrared camera, which employs indium antimonide array sensors developed for BMDO, weighs less than 10 pounds and features easy-to-use control electronics.

Portable Device To Detect Auto And Stack Emissions

With the help of BMDO funding, Pacific Advanced Technology's monitor could make checking your car emissions as quick and easy as filling your gas tank.

With Federal, state, and local regulators implementing stiffer environmental requirements, emissions monitoring is becoming increasingly important, not only for heavy industries but also in transportation—the largest consumer of carbon-rich petroleum in the United States.

In response to this concern, researchers at Pacific Advanced Technology, or PAT, (Solvang, CA) are developing a portable infrared monitor called the image multispectral sensor (IMSS), which they are directing toward automobile and smokestack emissions. This sensor's design has real-time monitoring capabilities, which make it a good solution for the nation's environmental need to frequently or continuously monitor the emissions from automobile exhaust.

The IMSS could also save time and a few steps in factory and industrial settings. As required by the Environmental Protection Agency, some industries must closely and frequently monitor their smokestack emissions. Using current tech-

nology, laboratory technicians usually sample emissions of the smokestacks several times each day and obtain results from an onsite chemical laboratory. The compact and portable IMSS, with its expected real-time capabilities, could eliminate

or reduce the need for personnel and laboratory facilities for such monitoring.

The device is also being marketed to monitor emissions from pharmaceutical laboratories producing amphetamines. Other applications include waste site monitoring, earth resources monitoring, and chemical/biological agent detection. The technology was originally developed under an Air Force-funded SBIR contract at Phillips Laboratory for space surveillance applications. BMDO enhanced the device, providing a design concept for a portable spectrometer that can support real-time data acquisition.

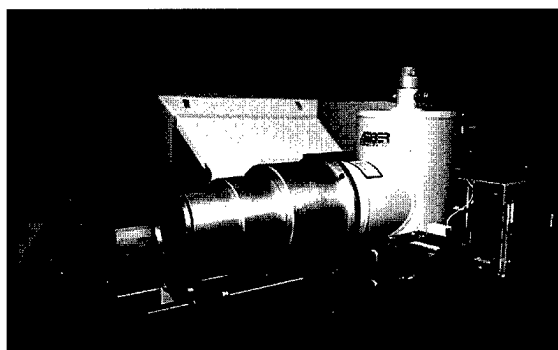
ABOUT THE TECHNOLOGY

The IMSS exploits advanced technology in diffractive optics and image signal processing. It images a scene and measures the spectral and radiometric content of all objects within the scene. Since it can measure the ratio of fuel gas mixtures from hydrocarbon-burning fuels, the device is especially appropriate for emissions monitoring.

While other spectral imaging devices have complex optics and require exact alignment, PAT uses a simple optical design. Rugged and portable, it is able to perform in the harsh environment of a space-based platform. The IMSS is also more sensitive and has spectral resolutions an order of magnitude higher than commercially available imaging spectrometers. It has a resolution of roughly 5 wavenumbers and can measure specified spectrums in the 2.5- to 5.0-micrometer range.

PAT's prototype laboratory system, the Hyper-Spectral Imaging Spectrometer, developed for the Air Force, has an $f/3.5$ lens with a 160-millimeter focal length and a full field of view of 2.3 degrees. PAT is currently using Amber's (Goleta, CA) indium antimonide focal plane array detector, another technology that is described in this report (see page 26).

So far, the prototype has been tested to measure the absorption spectra of acetone, auto exhaust emissions, and the fine structure in the emission of a butane flame. To certify the IMSS instrument performance, further testing will be conducted in the Kinetic Vehicle Hardware-in-the-Loop Simulator test bed at Eglin Air Force Base and the Naval Weapons Center at China Lake, CA.



■ Since the image multi-spectral sensor (pictured above) can measure the ratio of fuel gas mixtures from hydrocarbon burning fuels, the device is especially appropriate for emissions monitoring.

Monitor Detects Multiple Pollutants

On-Line Technologies is marketing its new analyzer primarily to users of environmental and process monitors.

Using BMDO-funded technology, On-Line Technologies or ON-LINE, (East Hartford, CT) has developed a product that can help technicians determine how much pollution their factories and industrial plants emit.

Projected to bring in over \$3 million in sales by the end of 1995, ON-LINE's product, the Multi-Gas Analyzer, can simultaneously analyze up to 50 gases, including carbon monoxide, sulfur dioxide, and ammonia. ON-LINE has also sold other related products, such as a combustion monitor that has brought in roughly \$400,000 in sales, using research funded by the BMDO SBIR program.

The original research was through a company called Advanced Fuel Research, or AFR, (East Hartford, CT), which developed Fourier-transform infrared (FT-IR) devices and compo-

nents—devices that give information about the composition, temperature, concentration, and dimensions of specific substances. Researchers at AFR recognized that the technology could be used for more than defense applications, and the company spun out

ON-LINE to manufacture and sell FT-IR devices for various environmental and industrial purposes.

For example, electric utilities, pulp and paper, and waste incineration industries can use FT-IR spectroscopy to monitor stack gases and processes. And industrial plants can use the technology for process control, such as measuring the temperature of oxides, which is a critical factor in making glass. In addition, technicians in the semiconductor industry can use the technology to determine temperature, composition, and film thickness during fabrication.

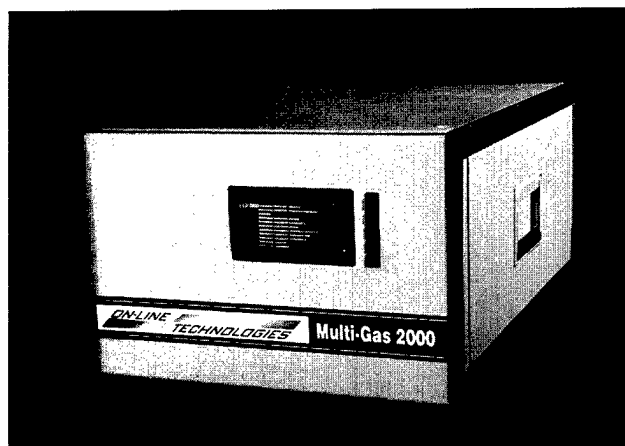
AFR, primarily focused on R&D, has eight BMDO-related patents (one of which has been licensed out). The company is investigating computerized feedback control for wafer processing based on FT-IR thin-film measurements; a field test has been performed. AFR has also conducted two successful field tests in glass plants where FT-IR was used to measure temperatures during manufacture.

ABOUT THE TECHNOLOGY

In the BMDO contract, AFR developed methods using FT-IR technology to monitor the deposition of high-temperature superconducting materials. These measurements allow researchers to see how the material's properties change as it is being formed. Film composition, temperature, and thickness as well as gas-phase measurements can be determined by this type of spectroscopy. AFR also developed a way to determine the temperature of oxides and other dielectric materials during this project.

FT-IR spectroscopy uses an infrared beam to acquire emission, reflection, and transmission spectra of a substance. Data are obtained simultaneously at all infrared wavelengths. To obtain the spectra, a computer processes these data in real time using a Fourier-transform algorithm. These spectra reveal information about the substance's composition, temperature, concentration, and dimensions.

ON-LINE's resulting product, the Multi-Gas Analyzer, has a wide range of capabilities that make it ideal for the environmental industry. For example, it has 10-parts-per-billion sensitivity with a 5-minute measurement time and 0.2-parts-per-million sensitivity for most species in about 1 second. In addition, it can display 10 different gas concentrations simultaneously and has automatic temperature and pressure compensation.



■ The Multi-Gas Analyzer can simultaneously analyze up to 50 gases, including carbon monoxide, sulfur dioxide, and ammonia.

Partnership Develops Green Manufacturing Technology

Industry, a Federal laboratory, and a university are working together to develop a fast, clean, and dry manufacturing alternative to wet chemical baths.

General Motors Research Division (Warren, MI), Los Alamos National Laboratory, or LANL, (Los Alamos, NM), and the University of Wisconsin (Madison, WI) are developing a cleaner manufacturing technology to make harder, more durable, and in many cases longer-lasting parts.

Called plasma source ion implantation (PSII), the team's technology can be used for a wide variety of machinery applications. PSII is a "dry" alternative to chrome plating that may provide significant environmental benefits over conventional methods for electroplating such as wet chemical baths. Rather than coating the material, this process actually changes the surface layer.

While GM is gearing its research toward the automotive industry, this process can also be used in virtually any heavy manufacturing application for metals where durability and

resistance to corrosion and wear are required. For example, it could be used to harden power plant and airplane parts, machine tools, and prosthetics.

These efforts are part of a

\$14-million, 3-year cooperative research and development agreement (CRADA) between the members of the team. Central to this research is a modulated radio-frequency power source technology that grew from the BMDO-funded ground test accelerator.

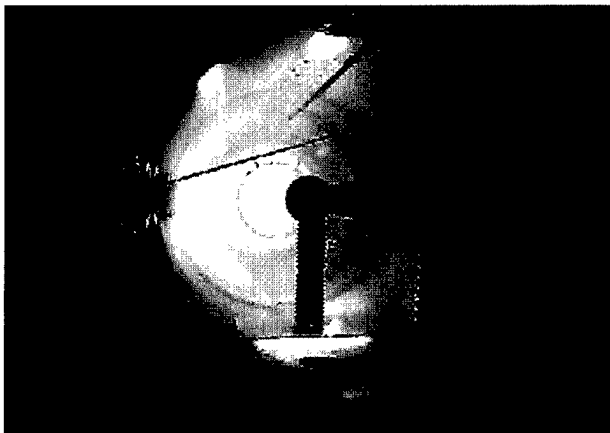
Ion implantation is not new. In fact, industry has been using line-of-sight implantation processes to dope silicon semiconductors for several years. But PSII, with its higher current levels—50 amperes, as opposed to 0.030 for line-of-site processes—is more practical for hardening machinery parts.

For some applications, PSII-treated parts can have longer lifetimes than those that have been chrome plated. For example, in a recent study comparing the service lives of steel tool punches using various treatments, the service life of nitrogen-implanted punches was more than 2 times greater than chrome-plated punches and 5 times greater than untreated punches. Since PSII is not a coating, adhesion and delamination are not concerns.

ABOUT THE TECHNOLOGY

The University of Wisconsin developed the PSII technique, in which a low-pressure gas, such as nitrogen, is injected into a steel vacuum chamber containing the material to be hardened. The nitrogen is ionized into a plasma using oscillating radio-frequency waves to strip electrons from the gas atoms. The material is exposed to short pulses of negative voltage. Positively charged ions are accelerated toward the negatively charged material and simultaneously bombard the material from all sides. The ions penetrate and modify the near-surface layers of the material.

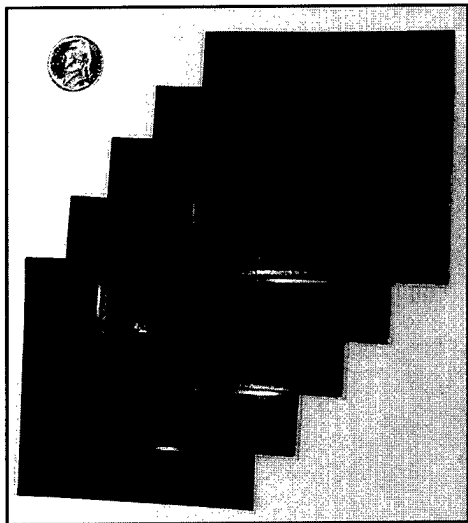
In the CRADA, LANL used a chamber that is 1.5 meters in diameter and 4.6 meters long, originally built for magnetic fusion research funded by the U.S. Department of Energy. Its large capacity allows hundreds of automobile parts or thousands of drill bits to be implanted in a single batch. This facility uses a power source with a peak voltage of 100,000 volts, a peak total current of 50 amperes, and an ion/total current ratio of 5 to 25 percent. The power source also has a pulse width of 20 microseconds and a maximum repetition rate of 2,000 pulses per second.



■ In a simulation of PSII, a cylindrical aluminum pipe is implanted with nitrogen.

Cleaner Batteries To Benefit Electronics Industry

Electro-Energy's less toxic battery can offer the portable-power industry a greener battery with a relatively high performance.



■ *Electrodes are placed flush against a thin conductive material, pictured above, which separates them to maintain individual cell compartments and conduct the current.*

The size of consumer electronics devices is steadily decreasing, while environmental concerns are increasing. Therefore, the need for smaller battery technologies—especially less polluting ones—has become more pronounced. Electro-Energy, Inc., or EEI, (Danbury, CT) is currently addressing these issues with its rechargeable bipolar nickel-metal hydride (Ni-MH) battery. This greener, highly efficient battery performs at least as well as conventional ones such as lead-acid batteries.

Ni-MH batteries have recently received considerable interest from the portable-power industry, in part because they use less toxic materials than lead and cadmium, which present environmental problems when manufactured or discarded. Therefore, manufacturers have started selling a monopolar version of the cleaner Ni-MH battery. But the monopolar design has

packing and energy density inefficiencies—not to mention a high manufacturing pricetag. On the other hand, EEI's bipolar design is more efficient and cheaper to produce.

From camcorders to electric vehicles, EEI's battery can be used in many applications that have a wide range of power requirements. The company is currently marketing the battery for uses such as laptop computers, cameras, and cellular telephones. These batteries could also replace primary cells (batteries that cannot

be recharged) for powering products such as flashlights. While rechargeable batteries are already available for such applications, their capacities are much lower than those of the bipolar Ni-MH battery or nonrechargeable ones.

In addition to a BMDO-funded SBIR contract for satellite applications, EEI has received funding from the U.S. Department of Energy for a battery in a notebook computer and from the National Institutes of Health for a ventricular assist system. The company has also been

awarded \$50,000 for market studies by Connecticut Innovations, Inc. or CII, a State-funded commercialization organization.

ABOUT THE TECHNOLOGY

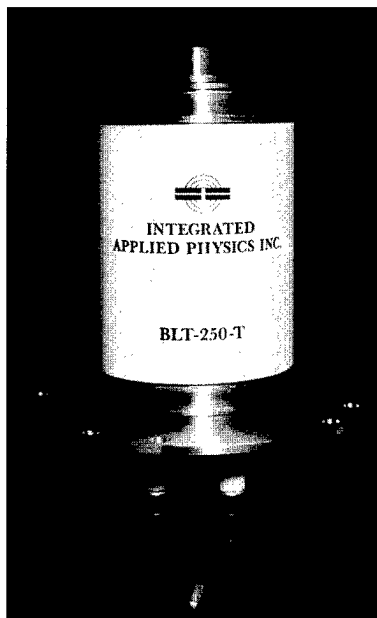
Bipolar technology has been investigated for years using other types of battery systems, such as lead acid. The bipolar battery cell has two electrodes: one positively charged and one negatively charged. These electrodes are placed flush against a thin conductive material, which separates them to maintain individual cell compartments and conduct the current. The electrodes are surrounded by an electrolyte. EEI has used various nickel materials for the positively charged electrode and a metal hydride alloy for the negative electrode.

The advantage of the bipolar design is that cells can be stacked and tightly packaged in series, where the negatively charged electrode of one cell shares the electrolyte of, and directly moves current to, the positively charged electrode of another cell, forming a highly efficient series connection. (Multiple cells for conventional rechargeable batteries, such as those in cars, are connected in series external to the cells.) Since multiple bipolar cells in series do not need external connecting components such as metal plates or wiring, this efficient design provides high energy and power densities with simplified packaging requirements. In addition, the bipolar design allows batteries to be fabricated in a wide variety of shapes for various electronics applications.

The performance of EEI's battery compares quite favorably with that of other types of batteries. It has a high practical energy density of 120 to 150 watthours per liter and 45 to 70 watthours per kilogram and can be recharged 500 to 2,000 times from a deep discharge. In comparison, lead-acid batteries have a practical energy density of 80 to 110 watthours per liter and 25 to 40 watthours per kilogram and can be recharged only about 500 times.

Pulsed Power To Provide Pollution Control

Integrated Applied Physics, Inc., a spinoff company from the University of Southern California, is targeting effluent gas control for its pulsed-power product.



■ IAP's backlighted thyatron, pictured above and to the right, dramatically reduces the size of accelerators, making them economically viable for pollution control, food irradiation, and semiconductor manufacturing.

For years researchers have investigated the ability of pulsed-power devices to zap contaminants from air, food, and chemicals, but, until now, commercialization prospects for many of these devices have been hindered by the technology's enormous size and price tag.

The University of Southern California, or USC, (Los Angeles, CA), has developed a pulsed-power switch called the backlighted thyatron (BLT) that could be used with accelerators to solve many of our most pressing pollution problems. From cleaning up flue gas to treating chemical waste, this product will make pulsed-power devices smaller and lighter, while cutting the price in half.

Integrated Applied Physics, Inc., or IAP, (Pasadena, CA) has spun off from USC to market this innovative research as well as other USC developments. IAP is most actively pursuing markets that use pulsed-power devices to control effluent gases. The BLT can produce high-voltage pulses from a particle accelerator, which chemically alters effluent gases into environmentally safe byproducts, more efficiently and at a lower cost than other switches. Other environmental applications for accelerators using the BLT include food irradiation and the transmutation of nuclear waste.

But the BLT has applications outside the environmental arena as well, since it can replace existing high-power switches in accelerators and lasers. In high-energy physics, for instance, the BLT can serve as a switch for magnets used in accelerators to transfer beams of high-energy particles between accelerators, control the beams, and dump the beams in an emergency such as a power failure.

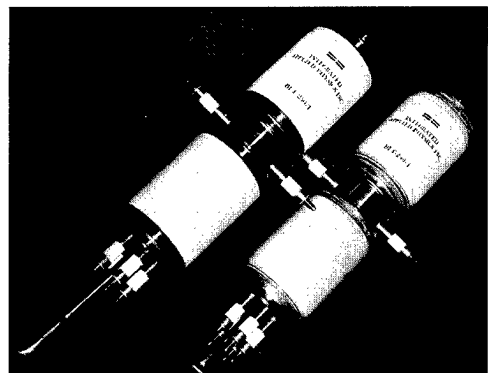
In addition, USC researchers have developed a new technique for BLT-based electrolithography, which can combine the resolution of x-ray lithography at a cost similar to that of optical lithography. Other applications for the BLT include sterilizing medical equipment and treating cancer patients with radiation therapy.

IAP has sold several prototype devices to date, mostly to research houses, and has three patents based on improvements of the technology. IAP has also continued research on pulsed-power technology through BMDO SBIR support for modulator development, as well as other SBIR program awards from agencies such as the U.S. Department of Energy.

ABOUT THE TECHNOLOGY

First developed at USC in the late 1980s, the BLT is an amplified high-power gaseous-discharge switch used in pulsed-power devices. BMDO funded BLT research at USC to help power directed energy weapons. Because the BLT is smaller than standard thyatrons and does not require standby power, it is especially attractive for long-term use in space.

By using an optical signal to trigger the switch instead of an electrical signal, the BLT can provide fast current rise (6×10^{11} amperes per second) and high peak current. The BLT features fast switching speeds and small size. In addition, it can conduct both forward and reverse current and requires little standby power (13 watts). IAP has continued development of the BLT and conducted research on solid-state power modulators. These gallium arsenide modulators provide a fast rise time in a compact package.



Highly Filled Materials Improve Toxic Waste Disposal

Among other applications, highly filled materials may be cheaper and safer than current methods to dispose of toxic liquids.

Located at Stevens Institute of Technology, researchers at the Highly Filled Materials Institute, or HfMI, (Hoboken, NJ) have found solutions to environmental problems, such as toxic waste disposal, using their new technique for processing materials.

When continuously processing materials in suspension, manufacturers rely on the materials' liquid phase for flow and processability. But when liquid is added, the material weakens and important properties, such as specific energy, change. To solve this problem, HfMI is investigating new ways to process materials with over 90 percent solid content by weight, or 60 to 70 percent by volume. HfMI calls such materials "highly filled."

BMDO's interest in this area has been to develop better solid rocket fuels with higher specific

energy. As a result, the IS&T program helped the Stevens Institute of Technology start HfMI and has funded research in highly filled materials.

As a spinoff of this rocket fuel research, HfMI has found a way to control toxic chemicals produced by the military. The hazardous

chemical is co-extruded with a polymer that chemically passivates the toxic agent. The polymer also encapsulates the hazardous chemical so that it can be more easily contained and transported.

HfMI has also developed highly filled materials that reduce electromagnetic fields (EMF) from transmission lines and other sources by 50 to 99 percent. With some studies linking EMF to adverse health effects, the need for EMF protection has recently generated considerable public concern. In this technology, HfMI has combined mathematical modeling with new composites to design materials that can insulate against EMF.

And with still more environmental uses, HfMI has investigated the possibility of producing new materials for batteries, recyclable plastics,

and timed-release insecticides for agricultural applications. The research center is also working with a major chemical company for improved honeycomb-based ceramics for industrial catalytic converters.

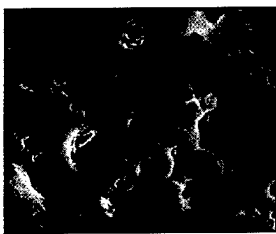
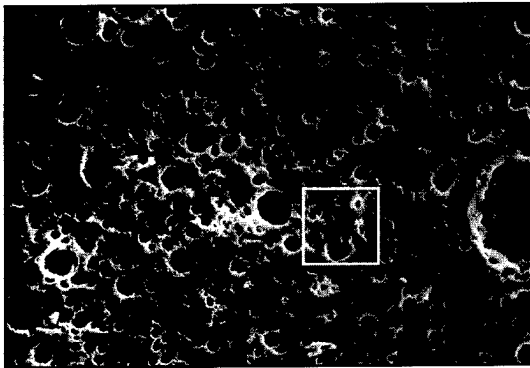
ABOUT THE TECHNOLOGY

HfMI develops new molding, forming, and other materials-processing technologies to produce high-density polymers, ceramics, and physical mixtures. The processed material may be either deformable or rigid, with a minimum level of porosity. In addition to developing new processing techniques, HfMI researchers are working to better characterize the properties of highly filled materials. This characterization involves studying three areas:

■ **Flow and deformation behavior.** Better understanding the flow and deformation behavior of highly filled materials has allowed HfMI researchers to write more accurate source codes for predicting the performance of processing devices.

■ **Interaction between the solid and liquid phases.** With their improved understanding of this interaction, HfMI researchers have been able to make suspensions that are deformable with the minimum of added liquid.

■ **Microstructure.** By studying the orientation and distribution of a material's microstructure, HfMI can better understand how the solid and liquid phases mix, once again allowing it to make deformable suspensions using as little liquid as possible.



■ One result of the HfMI's work is a method to encapsulate toxic chemicals in materials such as the one pictured above, improving the safety and lowering the cost of disposal operations.

**1994
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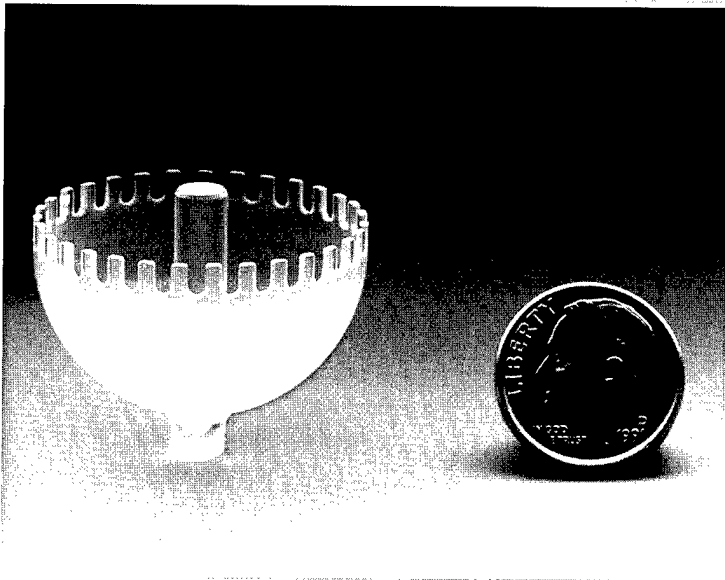
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*Delco Systems
Operations,
page 38*

Sensor Technologies

Sensors range widely in applications and functions, addressing a market estimated to be \$3 billion nationally and \$6.5 to \$7.1 billion worldwide. The largest segments of the market include temperature (such as infrared), pressure, and position sensors. About \$365 million in temperature sensors are sold each year in the United States, with growth projected to be about 5 percent. Internationally, this segment accounts for about \$500 million in sales at a growth rate of about 6 percent. Demand for all segments of the sensors market is growing at a rate of 8.1 percent in the United States and 9.2 percent worldwide, and over 1,400 companies are involved in producing sensor products.

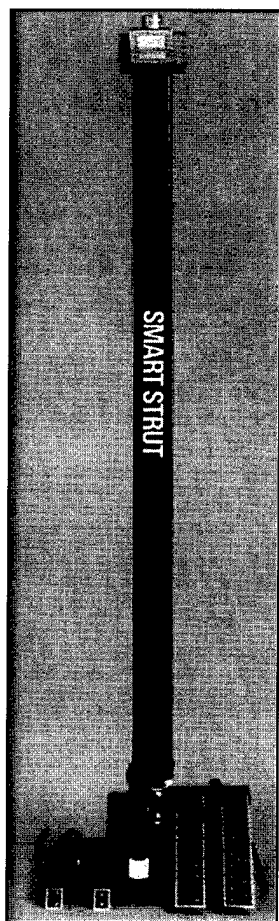
Through its Innovative Science and Technology (IS&T) program, as well as its Small Business Innovation Research (SBIR) program, BMDO has funded some of the most innovative sensor R&D for ballistic missile defense systems. As one of the first programs to be implemented by BMDO, sensor activities have focused on improving passive sensor capabilities and developing innovative approaches to track multiple targets with multiple sensors in a noisy environment. BMDO has also funded sensor development in other areas as well. Developers, in turn, have converted their BMDO sensor products to commercial uses such as oil drilling and automotive applications.

The following section describes the activities of companies and a Federal laboratory actively involved in commercializing their technologies, most of which have products on the market. Other sensor technologies are discussed in the environmental section of this report.

¹ All marketing figures cited from staff of *Sensors, The Journal of Applied Sensing Technology*.

Smart Patches Are On The Road To Automotive Applications

Noise reduction through windows at the flick of a switch? TRW's smart patches might do just that, but the company's first target is automotive applications.



■ The picture above is a cantilevered graphite beam with embedded PZT sensors and actuators. A set of pre-encapsulated sensor and actuator units is also shown.

TRW (Redondo Beach, CA) has developed a sensor technology, called the smart patch, that may give cars of the future a smoother ride. Through their Center for Automotive Technology, these researchers are injecting smart patch technology into their automotive product line, using it as a cheaper and better-performing active suspension system.

Active suspension systems for cars use special sensors to detect and dampen vibration from the road and other external sources. Current competition is the strain gauge device, a component costing several hundred dollars when manufactured at a rate of 20,000 a year. TRW's smart patches may prove to be a wiser choice for active suspensions because they reduce the cost of such systems to under \$100 each for the same annual output. They also perform better and are more rugged.

Smart patches, called piezoceramic patches in the scientific community, can be used to reduce noise and vibration or as sensors. TRW developed this technology through the Air Force Phillips Laboratory to actively dampen vibration in the Advanced Space Structures Technology Research Experiment (ASTREX) and in the forthcoming Advanced Control Technology Experiment (ACTEX) I and II space demonstrations.

But TRW's technology transcends automotive and defense needs and promises the potential of other new and innovative uses. For example, smart patches could reduce engine noise for aircraft and utilities by canceling bending vibrations (which are the source of engine noise) on the surface of engines.

These patches have more novel uses as well. For example, smart patches could be incorporated into window technology for buildings to dampen the noise of loud lawn mowers or city traffic—at the flick of a switch. They also could enhance CD-ROM performance and acoustics of stereo equipment—applications that are especially sensitive to external vibrations. TRW is pursuing joint ventures with companies that wish to insert active control technology into their commercial products.

ABOUT THE TECHNOLOGY

Smart patches are made from piezoelectric materials, which are dielectric crystals that generate electricity when subjected to mechanical stress. This piezoelectric material—also called PZT, for lead (Pb) zirconate titanate—is in the perovskite crystal family, which is noted for unusual electrical characteristics such as high-temperature superconductivity. PZT has piezoelectric coefficients that are much higher than those of silicon crystals, which are used in electronic resonators.

Used either for active control or as sensors, TRW's smart patches are lightweight, rugged, and insensitive to temperature, making them suitable for both space and terrestrial applications. They have a good frequency response and signal-to-noise ratio.

Smart patches have three components:

- **Sensors**, which transform elastic deformations into electrical signals;
- **Electronics modules**, which process the signals; and
- **Actuators**, which convert the processed signals into applied forces on the structure.

Pure Materials Lead To Improved IR Detectors, Sales

*Advanced Silicon
Materials, Inc.™,
spun off from Union
Carbide, in part to
produce and market
Ultra-Pure™ polysilicon.*

Advanced Silicon Materials, Inc.™, or ASiMI, (Moses Lake, WA) has recently spun off from Union Carbide (Danbury, CT) to make and market low-cost products that will improve infrared (IR) sensors. With applications such as smokestack and earth resources monitoring, IR sensors represent a market area that is expected to grow steadily in the next 5 years.

IR sensors require pure materials when they are manufactured; the purer the materials, the better the detectors. ASiMI's product, called Ultra-Pure™ polysilicon, is much purer than other polysilicon, which is used in semiconductor manufacturing to make such sensors.

ASiMI is primarily selling its patented Ultra-Pure™ polysilicon to companies that manufacture float-zone single-crystal ingots. Float-zone silicon wafers are used in photodiode detectors, sensors, charge-coupled imaging arrays,

high-power switches, power devices, and very efficient solar cells.

Although the commercial market for ultra-pure products is not large, the industry is growing quickly. Currently this new start-up company's product can be used in detectors and charge-coupled devices (CCDs) for envi-

ronmental monitoring. It also can be used for microelectronics applications such as power semiconductors and very high-density integrated circuits.

And since the purer materials improve device performance, new applications are on the horizon. For example, ASiMI is approaching other areas of the microelectronics market for silicon-on-insulator structures, substrates for heteroepitaxial and homoepitaxial films, advanced integrated circuit structures, and passive substrates.

In addition, nuggets of polysilicon can be used to make wafers of highly resistive Czochralski silicon ingots with low fault density. Caused by impurities, faults lead to high background noise and degrade the performance of detectors. They even can prevent CCDs from working. Since wafers made from Ultra-Pure™ -grade polysilicon are so pure, they can improve the performance of CCDs as well as high-density dynamic random access memory (DRAM) and bipolar/complementary metal-oxide semiconductor (CMOS) devices.

BMDO originally funded this research to improve the performance of IR detectors in detecting and tracking missiles. Union Carbide and Hughes Aircraft conducted joint development to improve the silane purification process and IR detector performance, respectively.

ABOUT THE TECHNOLOGY

ASiMI begins the process of making Ultra-Pure™ -grade polysilicon with metallurgical-grade silicon (about 98-percent pure). This is refined to semiconductor-grade silane by a distillation process that results in much lower impurity levels than are found in silane produced with other processing techniques. These low impurity levels are achieved through an innovative closed-loop process proprietary to the company. The polysilicon grown with this silane boasts substantial improvements in purity, representing an order of magnitude reduction in acceptor/donor levels—from current industry standards of 100 to 900 parts per trillion atomic (ppta) to less than 15 ppta.



■ Ultra-Pure™ -grade polysilicon is useful for detectors, charge-coupled devices, and microelectronics applications.

"Wineglass" Gyro Is Steered Toward Space And Oil Drilling

With patents and manufacturing facilities, Delco Systems Operations has already sold several of its Wineglass Gyros for space applications but is also steering the device toward oil drilling.

Gyroscopes, or gyros, have traditionally been used in airplanes and spacecraft to "remember" where the horizon is. Delco Systems Operations (Goleta, CA) has developed a gyro that may also be a faster and cheaper way to remember where the drill bit is for oil drilling operations.

With patents and manufacturing facilities, Delco has already fabricated and sold several of its hemispherical resonant gyros, or HRGs, for space applications such as a BMDO weapons platform. But the company is also pursuing other avenues for its device, including the oil drilling industry. Now small enough to fit in a drill bit, the HRG can reduce the time and cost of drilling while increasing precision. In addition, its ability to withstand very high temperatures and vibration makes it an ideal steering device.

For example, Delco's HRG can be used for measurement while drilling (MWD) techniques. The MWD technique is one solution for horizontal drilling, an important oil drilling concept that can help the United States maintain its endangered oil reservoirs by accessing oil that would have been difficult to obtain by conventional techniques. These techniques can also be used to extend pipelines and cable across rivers and other obstructions.

Delco's devices could replace the magnetometers that are currently steering MWD devices because, unlike magnetometers, HRGs are not affected by extraneous magnetic fields.

Magnetometers lose precision when any kind of iron ore is in the drilling area. And the closer to the North and South Poles one uses magnetometers, the weaker the signals are. Other magnetic fields, such as those from solar flares, also cause magnetometer sensing anomalies. HRGs' accuracy, on the other hand, is not affected by magnetic fields.

In addition to drilling applications, the HRG can be used in commercial and military avionics and space systems. In fact, BMDO originally

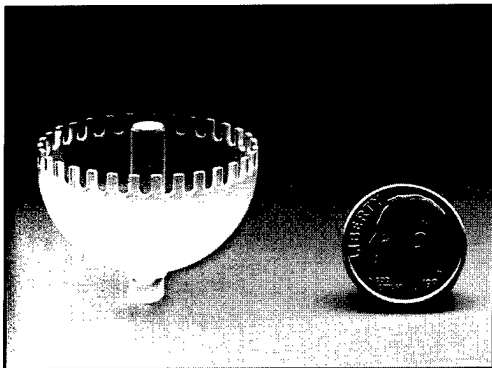
funded the technology for use in a space-based weapons platform. It is ideal for space-based applications because it has a relatively long life of 15 years.

ABOUT THE TECHNOLOGY

The HRG is sometimes called the "wineglass" gyro because in 1890 a physicist named G.H. Bryan used a wineglass in an experiment that led to the development of the HRG. Bryan observed that if he rotated the stem of a ringing wineglass, the standing wave pattern of vibration precessed (turned slowly) at a constant rate around the bowl of the glass. (Bryan made the wineglass ring by rubbing his finger around its rim.) Delco's HRG uses the principles of the precessing vibration that Bryan observed in the wineglass.

The HRG senses rotation with a single vibratory wave, continuously computing the inertially induced precession angle between the standing wave and the gyro case. The rate of precession varies with the shape of the shell. For hemispherical shells, the inertial precession factor is about 0.3. Therefore, if the standing wave pattern of an HRG fixed to an airplane was observed to rotate counterclockwise 3 degrees, one could conclude that the airplane had rotated $3/0.3$, or 10, degrees clockwise.

As a solid-state device, the HRG has no articulated moving parts. The hemispherical resonator is made of quartz (fused silica)—a strong material that can withstand vibration and heat. Because the fused silica resonator has an extremely high-Q (efficiency) resonance, the HRG is very precise. It can achieve a random walk of 0.0007 degrees/per root hour. In addition, the HRG requires only microwatts of power, as opposed to other gyro technologies, which require over 1 watt. Mechanical stresses on the unit in operation are minimal. It is also unaffected by radiation or short-term power outages.



■ The hemispherical resonator (pictured above) is made of quartz (fused silica)—a strong material that can withstand vibration and heat.

Device For Space Goes Underground To Drill Oil

From high in the sky to deep below ground: Oil companies may soon be sold on Honeywell, Inc.'s rugged, real-time device for steering oil drills.

Honeywell, Inc. (Clearwater, FL) is marketing two versions of a steering device called an inertial measurement unit, or IMU, which can sense motion and position for space and more down-to-earth applications, such as oil drilling.

Honeywell's technology has proved its worth on the Clementine space probe, a dual-use vehicle that combined the efforts of BMDO, the National Aeronautics and Space Administration, the Naval Research Laboratory, and Lawrence Livermore National Laboratory. This probe is providing new information about the moon while testing various BMDO-funded advanced systems.

But in addition to moon-mapping missions, the company has pursued another market area for its IMUs that is a little closer to home. Working

with two oil companies, Honeywell is making the IMUs rugged enough to help steer drill bits through the solid ground. The IMUs will enable more accurate drilling, and their real-time capabilities will eliminate the oil drillers' time-consuming procedure of pulling up the drill bit and pipe and sending down a separate

measuring device. Drillers use drill bit position information to verify their drilling relative to geological surveys or geographic boundaries.

Honeywell has also targeted its device for lightweight communications satellites. The larger version of the IMU is two-thirds lighter and 75-percent cheaper than current equipment for sensing position. Engineers have upgraded the IMU with radiation-hardened components to survive the harsh environment that satellites face in low-earth and geosynchronous orbits. They are also planning to upgrade the smaller unit.

Developed through a mixture of internal R&D funds and contracts through the Lawrence Livermore National Laboratory for the Brilliant Pebbles missile defense program, the IMU has

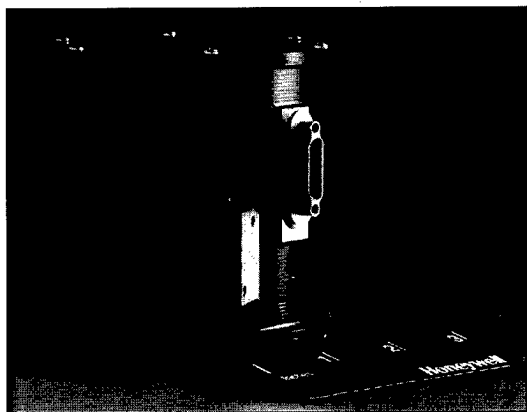
been used in a number of defense projects. Honeywell has patents on key aspects of the position-sensing design of the IMU.

ABOUT THE TECHNOLOGY

Honeywell's developments provide a choice: One version of the IMU is the GG1308, which is 90-percent smaller and lighter than its flight-qualified predecessors. Honeywell also offers a more accurate but larger version of the IMU called the GG1320, which is still much smaller than current IMUs.

In their devices, Honeywell engineers use three ring-laser gyros (RLGs) to determine angular velocity and three state-of-the-art accelerometers to determine linear velocity. In 1984, the development began on the present RLG design, with two helium-neon lasers that beam light into a triangular mirrored course. A photodiode receives both beams—one traveling clockwise, the other counterclockwise—to be compared by the IMU's electronics. The IMU measures phase shifts between the rotating beams introduced by rotation of the platform and translates them into rates, as the light arrives at different times at a detector. (Light traveling in the direction of rotation takes longer to arrive than light from the same beam traveling against the rotation.)

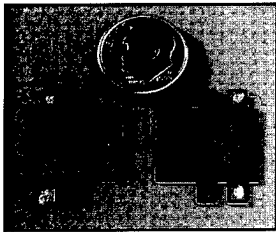
The three RLGs are grouped together and mounted on a torsional spring that introduces angular motion, or dither, to each RLG. This motion is necessary to impart a frequency difference to the light beams, identifying them when the platform is at rest. Grouping the RLGs together on a single-dither mechanism allowed Honeywell to significantly reduce size and weight. The smaller IMU weighs about 1 pound, with a 3.27-inch diameter and a 3.2-inch height, and accurately senses angular velocity within 0.5 degree per hour.



■ Honeywell's smaller IMU, the GG1308, is 90-percent smaller and lighter than its flight-qualified predecessors—it weighs only about 1 pound and stands 3.2 inches high.

Smaller Sensors Address Industrial Needs

The Jet Propulsion Laboratory's infrared sensor, using scanning-tunneling microscopy, won a 1993 "R&D 100" award from R&D Magazine as one of the year's 100 most significant innovations.



■ Like all electron-tunneling sensors, these components of the electron-tunneling accelerometer can be mass-produced using inexpensive silicon micromachining techniques.

From monitoring the manufacture of automobiles to imaging industrial processes, the small and sturdy sensors at Jet Propulsion Laboratory, or JPL, (Pasadena, CA) are being applied in areas where small size and accuracy are important. The laboratory is currently working with industry and other government agencies on state-of-the-art magnetometers, infrared (IR) sensors, and accelerometers.

The technology enabling these devices stems from BMDO-funded research on tiny transducers, that, unlike conventional ones, get more accurate as they become smaller. Transducers are an essential component of some sensors, which convert physical signals such as acceleration or pressure, into electrical signals.

JPL's research has landed it a licensing agreement with Eaton Corporation (Milwaukee, WI) to develop magnetometers for harsh industrial environments such as automobile manufacturing. For example, the magnetometer could passively monitor connections of spark-plug wires. Eaton is paying JPL to make wide-bandwidth sensors that measure magnetic fields. The Laboratory has also built two less-rugged versions of the magnetometer for the Navy, one of which is 3 times more sensitive than competing magnetometers.

JPL researchers are also making cheaper, tougher, and smaller uncooled IR sensors, called Golay cells. One of the big problems with conventional IR sensors is that they require cooling components, which add to the cost and size of the system. JPL's Golay cells could answer IR-sensor needs where cryocooling is impractical—for example in medical thermometers, industrial process imaging, night-vision goggles, and laboratory spectroscopy. And while some uncooled IR sensors do exist, they are larger and not nearly as sensitive as JPL's technology. Using the BMDO transducer, JPL was able to develop a device 3 to 5 times more sensitive than the leading competitor for uncooled IR detection.

In addition, JPL is converting the transducer technology to develop an easy-to-manufacture electron-tunneling accelerometer (ETA). With its small size, high accuracy, and low power requirements, the ETA matches the needs of

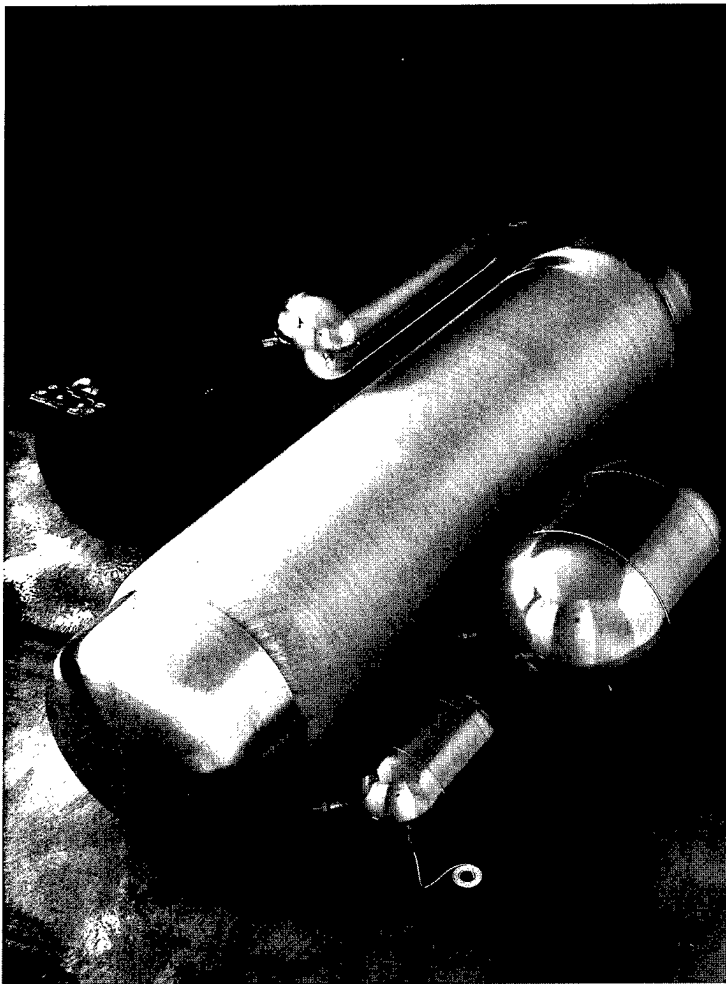
many applications requiring compact devices, such as aircraft, submarines, ships, and robotics. It can also be used for seismology and vibration-control systems. The transducer for the ETA is about 10 times more accurate than other miniature motion transducers and only slightly less accurate than accelerometers as big as a wastebasket. JPL has received patents for the tunneling transducer and the three electron-tunneling sensors.

ABOUT THE TECHNOLOGY

JPL's transducer design is based on scanning-tunneling microscopy (STM), a technology that has been widely used since 1982 to map the atomic bumps and valleys of material surfaces. Unlike conventional transducers (which are less sensitive when miniaturized), the tunneling transducer must be small to measure electron-tunneling currents, enabling accurate miniature sensors.

STM, as its name implies, is based on the concept of electron tunneling. According to quantum theory, if one lightly throws a ball at a solid wall, the ball could pass through the wall. Of course the chances are pretty remote; you would have to throw the ball at a wall every second for trillions of years before succeeding. The chances are more significant, however, for atomic-sized particles tunneling through a very thin barrier. With a barrier width of one-billionth of a meter, tunneling has about a one-in-a-million chance of occurring—not such a remote event with billions of electrons trying to tunnel. In such cases, enough electrons can break through the layer to make a measurable current.

Invented at IBM-Zurich, STM measures the separation between a fine-pointed stylus and a surface. In an STM, a tiny electrode tip moves a few angstroms over a surface. A small voltage difference is applied between the tip and surface, small enough that electrons can only pass from the tip to the surface by tunneling. This tunneling current gets stronger as the tip moves closer to the surface, so the distance between them can be measured.



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Industries,
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Energy Technologies

In 1990 (the latest data available), the nation spent roughly \$473 billion for energy, with petroleum products accounting for about half this number. Electricity sales totaled \$138 billion, and utilities invested over \$2.2 billion in demand-side management practices. Demand-side practices are approaches to help level electricity loads during peak usage periods; they often include energy-efficient technology.

Manufacturing accounts for a large percentage of total U.S. energy consumption, and manufacturers over the last decade have increasingly focused on their ability to cope with fluctuations in energy supplies and prices by switching to alternative sources. Other technologies that improve the efficiency of production processes are also gaining the interest of manufacturers. Such technologies either speed up or reduce the need to repeat specific processes, and therefore they indirectly conserve energy.

On the production end, 20 major energy companies in 1991 accounted for 27 percent of the profits and 18 percent of the assets of *Fortune's* 500 largest U.S. industrial corporations. Most of the companies' \$46.4 billion in new investments in 1991 included in the Financial Reporting System (FRS) was directed toward petroleum activities. (The FRS collects financial data from the major energy-producing companies.)

BMDO has funded many technologies that can contribute and have contributed to commercial energy applications through programs such as the Small Business Innovation Research and the Space Power and Power Conditioning programs. The following section describes seven of these technologies, with customers from utilities, food production, satellites, and public transportation.

¹Usage and expenditure figures obtained from the August 1993 *Annual Energy Review* produced by the Energy Information Administration for the U.S. Department of Energy, except for the demand-side management expenditures, which come from the *Electric Power Annual*, 1992 (produced by the same group).

Solar Hologram Device May Compete With Coal

Northeast Photosciences is breaking down the cost and performance barriers associated with large-scale solar-generated electricity.

Will your air conditioner soon run on the sun? Northeast Photosciences' (Hollis, NH) hologram device may make solar cells cost-competitive with coal-burning power plants for electric utilities.

Previously, the low efficiency and high cost of generating electricity with photovoltaic (PV) cells have prevented utilities from using them on a large scale. But Northeast Photosciences has developed a hologram device expected to increase the efficiency of PV power generation to a lofty 32 percent. And the system's projected power-generation cost—5 to 6 cents per kilowatt-hour—could compete with current fossil-fuel power plants, if environmental cleanup is considered.

In addition to electric utilities, the PV hologram devices could supply power to electricity users at remote locations, such as farms, recreational parks, homes, and factories not connected to the

utility grid. The technology can also be used for space-based applications such as satellites.

Northeast Photosciences' hologram device efficiently focuses sunlight onto solar cells. The holograms are relatively cheap to manufacture and reduce the often problematic cooling

needs associated with PV cells, thereby increasing their efficiency. And like other PV technologies, the PV hologram system would benefit the environment tremendously because it can generate power without producing polluting emissions. It can also help conserve our vital domestic natural resources, such as coal, natural gas, and uranium.

Researchers at Northeast Photosciences have had numerous discussions with Sandia National Laboratories (Albuquerque, NM) about terrestrial uses, such as Sandia's Baseline 3 Photovoltaic Concentrator Module. They are now planning to demonstrate the holographic system to verify that it meets cost analysis projections.

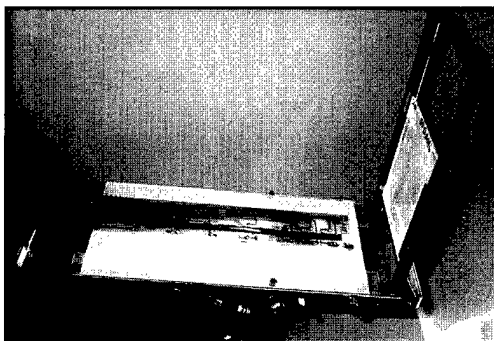
The researchers are also discussing opportunities with the Naval Air Warfare Center (China Lake, CA). The holograms could be used in SELENE, a program to beam power to a satellite solar power system using a free electron laser. The solar holograms on the satellite would usually convert solar radiation to electrical power, but when larger amounts of power are needed the solar hologram would receive power from the ground-based laser. Northeast Photosciences has also had discussions with a venture capital investor interested in improving the performance of solar cells.

The BMDO SBIR program funded research in PV hologram power because it is an ideal technology for space-based power generation, where light weight, high efficiency, and infrared avoidance are important considerations. Northeast Photosciences is in the process of applying for a patent for the hologram system.

ABOUT THE TECHNOLOGY

The company's single-element hologram spectrally separates light and focuses it perpendicularly to the hologram in a thin concentrated line. By spectrally separating the light, the hologram lets two or more different solar cell types absorb only those wavelengths that each cell type most efficiently converts to electrical power. The side focus also improves solar cell efficiency by eliminating shadow effects.

Another advantage of the technology is reduced cooling requirements. Spectral separation prevents overheating by diffracting unwanted infrared radiation away from the cells. The side focus replaces the common but difficult-to-cool stacked design with a side-by-side design.



■ Northeast Photosciences' holographic prism separates sunlight into different wavelengths, allowing solar cells to absorb only those that they best convert to electrical power. The prism also makes solar cells more efficient by eliminating shadow effects and reducing cooling requirements.

Material Becomes Hot Item For Pizza Delivery

The material is already being used by Pizza Hut, but Hayes and Associates is warming up to other market areas as well, such as thermal tableware and active insulation in homes.

Keeping pizzas crisp and hot for about 2 hours, Hayes and Associates (San Diego, CA) has licensed its heat storing material to PepsiCo, Inc. for Pizza Hut delivery operations. Hayes' material allows hot pizza to be served at ball games and airports, without an oven or even a microwave onsite.

How does the pizza delivery system work? The pizza sits on a warming tray developed by Hayes that stays just hot enough—but not too hot—to maintain the pizza's crispness. The pizza and tray are then placed in an insulating container and delivered to the customer.

The nonexclusive, limited-scope license guarantees Hayes a 6-figure slice of the pie. And while Hayes cannot sell to other pizza companies for a year, the company can pursue, and is pursuing, other out-of-scope licensing agreements, such as one with a large plastics manufacturer for thermos-like applications.

In addition to pizza delivery, the material can be used for consumer products, such as winter outerwear, food warmers, hot cups, stadium cushions, or any portable warm container.

These products, when heated, could be engineered to maintain a specific temperature for a specific time. So, for example, people could warm their gloves in the microwave before going to a frosty football game.

Hayes is also considering this material for thermal

control in homes, electronics, and solar- or nuclear-powered electric generators. For example, this material could serve as active insulation for homes in temperate climates, where the thermally active material would absorb heat during the day and then release it slowly at night. Significant design studies are needed for such an application.

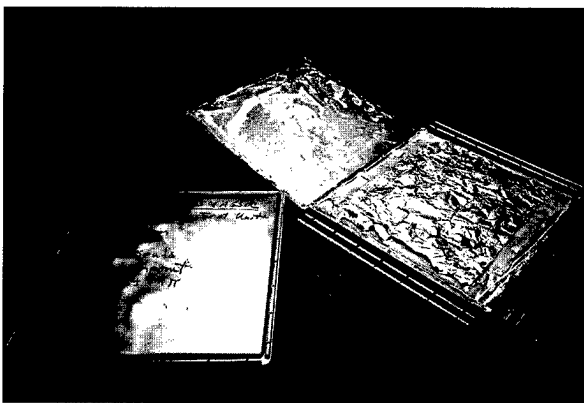
BMDO was interested in materials for fast aerospace vehicles that can absorb large quantities of heat with limited overall temperature rise. The Hayes thermochemical materials can retain heat orders of magnitude better than other materials given the same weight. But while the material's ability to store heat was a BMDO focus, its real value in the commercial marketplace is its ability to retain and release heat in a controlled manner.

ABOUT THE TECHNOLOGY

Hayes and Associates' material can be thought of as the high-temperature analog of the freezer cold pack that one might put in a picnic cooler. The hot pack releases heat at a constant temperature over a sustained time, just as a cold pack absorbs heat at a constant (lower) temperature. The key aspects of Hayes' patented technology are active materials that retain lots of heat and the ability to tailor the material to temperature and time-at-temperature requirements.

The system consists of an inner region of thermally active material sandwiched between protective outer layers of plastic or metal. The inner section contains a polymer that undergoes a thermochemical reaction, or phase change, to absorb and release heat at a critical temperature. Often the polymer is implanted in a mesh, fabric, or composite structure. The resulting material system is relatively lightweight and can be fabricated into flexible or rigid flat plates, panels, or complex shapes.

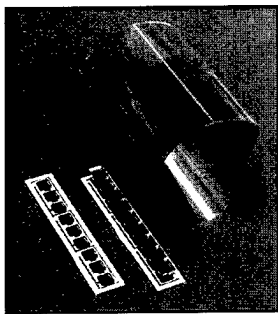
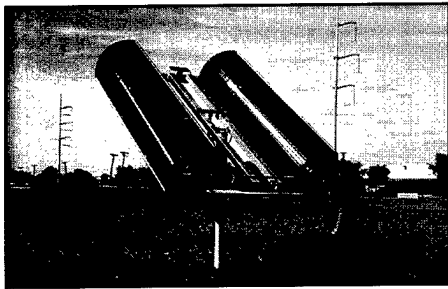
When heated, the composite material reaches the critical point and continues to absorb more heat until saturation. At that point, the temperature may increase further. On cooling, the reverse occurs, with the temperature rapidly falling to the critical point and remaining at that temperature for an extended time until the internal thermochemical processes have been exhausted.



■ Shown above are warming trays developed by Hayes and Associates for pizza delivery operations.

ENTECH Demonstrates A Sunny Commercial Success Story

*On the grid, off the grid:
ENTECH is focusing on
solar-powered electricity
with the SUNLINE™
stand-alone unit and
utility-scale SolarRows.*



■ Above: ENTECH's solar concentrator arrays focus light to the strength of many suns onto a small area of solar cells.

Below: Because of its arched design, the line-focus Fresnel lens directs 90 percent of the incident light to the solar cells, reducing the need for stringent lens manufacturing and installation tolerances.

Photovoltaics, sometimes called solar cells, have been used since the 1950s to convert solar energy to electricity. The sun is an abundant energy source that could be ideal for generating electricity on a large scale, and it's free. In fact, the amount of solar radiation that reaches the earth's surface in 3 days is equal to the total energy content of all known supplies of fossil fuels. But our ability to harness all this energy has been very limited.

ENTECH, Inc., (Dallas-Fort Worth Airport, TX) is improving sun-harnessing capabilities with its product, the SUNLINE™ stand-alone

power unit. This product is designed for electricity users not hooked up to the utility grid. The company's photovoltaic (PV) concentrator arrays can efficiently harness solar energy using a technology called the line-focus Fresnel lens. The cylindrical Fresnel lenses focus sunlight on PV cells to the

intensity of many suns, reducing the amount of costly PV cell material needed for a given energy output.

In addition to off-the-grid sites, ENTECH is testing larger units called SolarRows at utility sites for large-scale electricity generation. The company has installed a 100-kilowatt solar power plant for the Texas Utilities Electric Company at its renewable energy demonstration and test facility. In addition, other test systems have been installed for Sandia National Laboratories, Pacific Gas & Electric, and the Tennessee Valley Authority.

A smaller version of ENTECH's Fresnel lens can be used in space-based applications. The line-focus Fresnel arrays would reduce launch costs because the concentrator array, as compared with flat-panel solar arrays being considered for a space station design, is half the weight and size for the same power output. In a test aboard the space shuttle, ENTECH teamed with JX Crystals, Inc., a spinoff of Boeing, to produce a unit where solar cells achieved over 30-percent efficiency. (Commonly used PV cells made from silicon have an efficiency of 13 percent in converting sunlight to electricity.)

BMDO awarded SBIR contracts to ENTECH to develop the line-focus Fresnel lens and its predecessor, the minidome Fresnel lens, for space-based applications. The National Aeronautics and Space Administration has also funded the lens' development to produce a more efficient, lightweight solar array. In addition, ENTECH is teaming with the U.S. Department of Energy to solve problems in manufacturing its technology in the 5-year Photovoltaic Manufacturing Technology (PVMat) program.

ABOUT THE TECHNOLOGY

Most solar arrays are flat surfaces covered with PV cells made from silicon or some other more expensive materials. When these arrays, known as planar arrays, are pointed correctly, each cell receives the light of the sun. Concentrator arrays, on the other hand, focus light to the intensity of many suns onto a small area of PV cells and can generate more power than planar cells for a given area. Using such arrays, systems may need as little as one one-hundredth of the PV material to generate the same amount of electricity. The costly PV material is replaced by a cheaper lens and heat dispersion material.

ENTECH's line-focus Fresnel lens has an ultrathin lightweight design. Its inner surface is made of microscopic prisms that shape the light like a heavy, spherical lens. Because of its arched design, the lens directs 90 percent of the incident light to the solar cells, reducing the need for stringent lens manufacturing and installation tolerances.

In the SUNLINE™ stand-alone power unit, two Fresnel lens modules are mounted on a platform that tracks the sun in two axes, producing 1,000 watts at peak output. A SolarRow, used to make power for the utility grid, consists of 72 modules, each 3 feet by 12 feet, attached to a computer-controlled sun-tracking structure that is 341 feet long. ENTECH can assemble enough 25-kilowatt-producing SolarRows together to produce electricity for utility-level power generation.

Cleaner Battery To Provide Power For Global Communications

Eagle-Picher Industries is supplying a smaller and less costly nickel hydrogen battery for Motorola's IRIDIUM^{TM/SM} satellite network, a worldwide personal communications system.

Replacing its nickel cadmium predecessor, the nickel hydrogen battery is becoming standard for electrical storage in satellites. Its longer service life, lighter weight, and high resistance to accidental abuse (such as overcharging) provide a clear advantage over the battery's more conventional counterpart.

In addition, the environmental impact of the nickel hydrogen battery is relatively benign as compared with the nickel cadmium battery, which requires processing cadmium, a heavy metal. The challenge now is to reduce the cost and size of the nickel hydrogen battery so that it will fit into the newer, smaller satellites being designed.

Johnson Controls, Inc., (Butler, WI) developed a nickel hydrogen battery that is significantly smaller and lighter than previous nickel hydrogen designs while costing 20 to 40 percent less.

Its life-cycle costs are also competitive because it has a long life and requires no maintenance. Patents for the batteries are now held by Eagle-Picher Industries (Butler, WI).

These batteries have been slated to store and deliver power in each of Motorola's IRIDIUM^{TM/SM} satellites, which are part of a new network for worldwide personal communications. In this project, the company is supplying the Lockheed Missile and Space Company, the satellite developer, with 10-inch-diameter batteries for Motorola's Satellite Communications Division.



■ The performance of the nickel hydrogen battery (pictured above) was improved by combining all the cells into a single pressure vessel. The battery used in the Clementine space mission was 23 centimeters in diameter and had a specific energy of 47.1 watt-hours per kilogram.

Closer to home, the advanced nickel hydrogen battery's low cost is marking it as a potential terrestrial technology to store power for industrial applications, aircraft starters, and telecommunications repeater stations. It also can be used to store solar-generated power.

BMDO supported the development of the battery to provide power for the BMDO-funded Clementine space probe, proving its capability

on its first spaceflight. The 15-ampere-hour battery selected for Clementine is about 23 centimeters in diameter, weighs 9.5 kilograms, and has a specific energy of 47.1 watt-hours per kilogram. It is also fully rechargeable from a totally depleted state. Both the National Aeronautics and Space Administration and the Naval Research Laboratory have purchased batteries for testing.

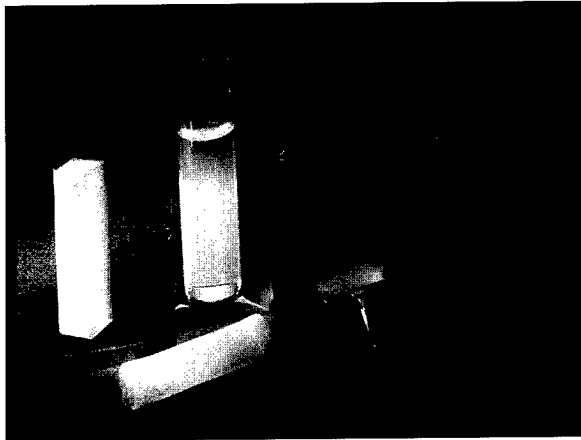
ABOUT THE TECHNOLOGY

Although an improvement over nickel cadmium batteries, early nickel hydrogen batteries used individual pressure vessel (IPV) cells to store hydrogen gas. The design of these batteries made them bulky and expensive to launch. The performance of the nickel hydrogen batteries was improved by combining all the cells into a single pressure vessel called the single pressure vessel (SPV) battery. For the same performance, this battery is significantly smaller and lighter than an IPV battery.

The SPV battery is available in a 5- or 10-inch diameter size, depending on the ampere-hour capacity required. Its length depends on the number of cells connected in series to provide the desired voltage. The pressure vessel is made from either Superalloy 718, a high-strength nickel alloy used in aerospace batteries, or from a filament-wound polymer composite with a thin, stainless-steel liner.

Carbon Aerogels Empower Commercial Uses

With help from the Technology Reinvestment Project, Polystor Corporation is commercializing a compact, low-cost power source called the aerocapacitor.



■ LLNL has developed a new family of aerogels, called organic aerogels. Carbon aerogel is pictured second from the left.

Working closely with researchers at Lawrence Livermore National Laboratory (LLNL), Polystor Corporation (Livermore, CA) is commercializing the laboratory's patented power device, which can provide the punch needed for new electronic devices, such as hand-held medical tools.

This electrochemical double-layer capacitor (EDLC)—called the aerocapacitor—can store and release lots of energy with a lightweight, highly porous material called aerogel. Using aerogel made from carbon, researchers have increased energy density by 10-fold over current capacitors.

Polystor's first step toward commercialization is a \$1.9 million Technology Reinvestment Project (TRP), funded by the Advanced Research Project Agency. The TRP is designed

to develop dual-use technologies, such as Polystor's aerocapacitor, through government-industry interaction. Other participants in the aerocapacitor TRP effort include a commercial supplier of power supplies, Power One, and the California Trade and

Commerce Agency. Rockwell International and Aerojet, both consumers and suppliers of capacitors, are also participating.

When packaged together, high power and high energy density are coveted qualities for capacitor technology. Therefore, researchers at LLNL have taken advantage of carbon aerogel's highly porous characteristics to join these qualities in one device. Other EDLCs have been limited to applications that require only low energy densities, such as memory retention in integrated circuits.

Polystor's capacitor is also smaller than others with the same output and can potentially be manufactured at low cost for widespread use.

And as with other EDLCs, cycle life is generally only limited by the device packaging, because there is no chemical reaction.

The team's breakthroughs have translated to smaller and better-performing power sources for applications such as hand-held medical tools, electronic devices, and power-assisted technologies for transportation. Aerocapacitors can also be used for power conversion, computer backup, and pulsed-power applications.

BMDO originally funded this research in 1992 and 1993 at LLNL to develop lightweight batteries for its space power program. A small portion was also funded by the U.S. Department of Energy.

ABOUT THE TECHNOLOGY

Those familiar with the light, highly porous material called aerogel may commonly think of some of the more talked-about energy applications such as refrigerator insulation; but its qualities also make it attractive for power technologies.

Like other aerogel materials, carbon aerogel is highly porous and has a solid matrix composed of interconnected nanometer-sized particles. Its many pores, both mesopores and micropores, give this material the high surface area needed to provide a large capacity. In addition, the carbon material acts as a suitable conductor for power applications.

Carbon aerogels exhibit high power and energy densities with capacitance densities of several tens of farads per gram and cubic centimeter. In prototype devices, the aerocapacitor offers a 10-fold increase in energy density over current capacitors, and stored energy can be released rapidly and efficiently, resulting in high power densities of up to 7.5 kilowatts per kilogram.

Ztek's Zirconverter® Zooms Ahead For Utilities, Cars

Like most fuel cells, Ztek Corporation's Zirconverter® can use hydrogen—the most abundant element in the world—as a fuel source for utilities, buses, and automobiles.

Ztek Corporation (Waltham, MA) is developing a cleaner alternative to internal combustion engines called the Zirconverter®.

This compact device can generate electricity using petroleum or non-petroleum-based fuels—and it emits little or no pollution. In fact, using hydrogen as a fuel, its byproducts are water and very small amounts of carbon dioxide. The Zirconverter®, therefore, can give utility companies and car makers the flexibility to choose cleaner fuels. And as an added advantage, its simple design and low-cost materials make it relatively cheap to manufacture.

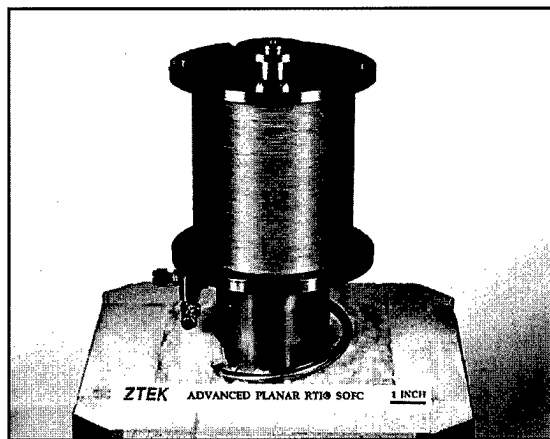
While BMDO funded fuel-cell research through an SBIR contract to power space-based components, this research, as applied to the Zirconverter®, is ideal for powering utilities as well. Projected customers from the utilities are already working with Ztek to support

development of the Zirconverter®. The company plans to have a 250-kilowatt system available to generate power by 1995 and a 2.5-megawatt system available in 1998.

What's the utility advantage? Because this fuel cell can efficiently recover high-quality byproduct

heat (1,000 degrees Celsius), utilities can use this device for multimegawatt central power plants and the repowering of existing power plants.

Ztek's Zirconverter® can also extend the range of buses and automobiles. And by recharging the batteries, this device produces heat that can be used for space conditioning or climate control inside the vehicle. (Cooling can be supplied by using heat-actuated air-conditioning equipment.) Since it can use any one of a number of different fuels, the Zirconverter® could allow electric vehicles to be marketable, even without wide availability of unconventional fuels.

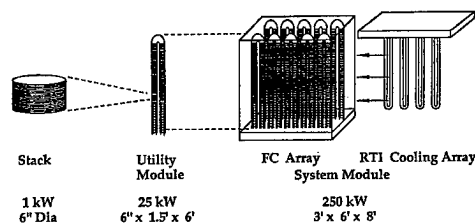


■ Ztek's SOFC needs no recharging and creates no environmentally harmful byproducts.

ABOUT THE TECHNOLOGY

BMDO originally funded research at Ztek for advanced planar solid oxide fuel cells (SOFCs). Ztek's SOFC creates electrical energy through an electrochemical reaction with gaseous fuel and oxidizer. The fuel, usually hydrogen, is supplied by an outside source and reacts with the oxidizer in the cell, creating electrical energy and leaving water as a byproduct. The SOFC will provide electricity as long as fuel is available, needing no recharging and creating no environmentally harmful byproducts.

Ztek has applied this research to the Zirconverter®, which is an SOFC stack composed of thin plates of zirconia electrolyte alternately arranged with electrical interconnector plates. This design contains internal gas passages that provide the oxidizer and fuel supply and allow spent gases to exhaust. For more versatility as an energy source, Ztek's Zirconverter® has more than one operating mode. First, it can work in an electrochemical loop to generate electric power from heat; or, it can work in a regenerative loop, generating electricity from stored fuels and producing byproducts that can then be transformed to replenish the original fuels. The result is an adaptable, lightweight, high-energy power source.



■ Ztek plans to have a 250-kilowatt fuel cell system available to generate power by 1995.

Siemens is using the Jet Propulsion Laboratory's sorption compressor to develop a prototype air conditioner for Los Angeles Metro Transit Authority subway cars.

In conjunction with Aerojet Electrosystems (Azusa, CA), Jet Propulsion Laboratory, or JPL (Pasadena, CA) is developing a more efficient gas heat pump that can compete with its electric counterpart. Using BMDO-funded technology for space-based sorption compressors, this technology not only could reduce heating and cooling bills for homes and businesses, but could also provide essentially free domestic hot water.

it emits smaller amounts of greenhouse gases and other pollutants per unit of energy output than coal-burning power plants and it allows non-ozone-depleting refrigerants to be used. For utilities, the sorption compressor provides load management benefits—it

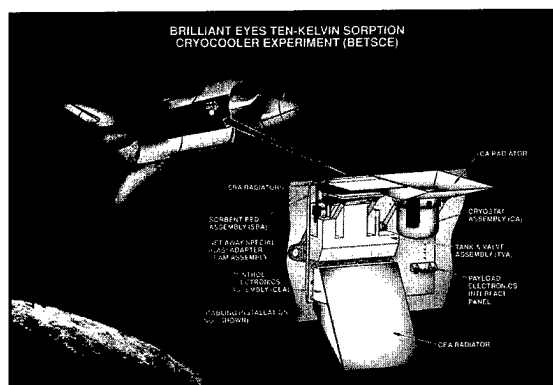
In addition, this device offers noiseless and vibration-free operation, and since none of the moving parts can wear out except for the low-frequency valves, it is expected to be reliable and have a relatively long life. The compressor also uses long-lived, reversible physical reactants instead of corrosion-prone and potentially life-threatening chemical reactants.

technology. So far, this collaboration has led to a contract with Siemens to develop a prototype air conditioner for Los Angeles Metro Transit Authority subway cars. With plans to commercialize the sorption compressor after it is completed, Aerojet is currently receiving an exclusive worldwide license for the technology. And as part of its defense conversion activities, Phillips Laboratory will provide testing services for all future prototypes.

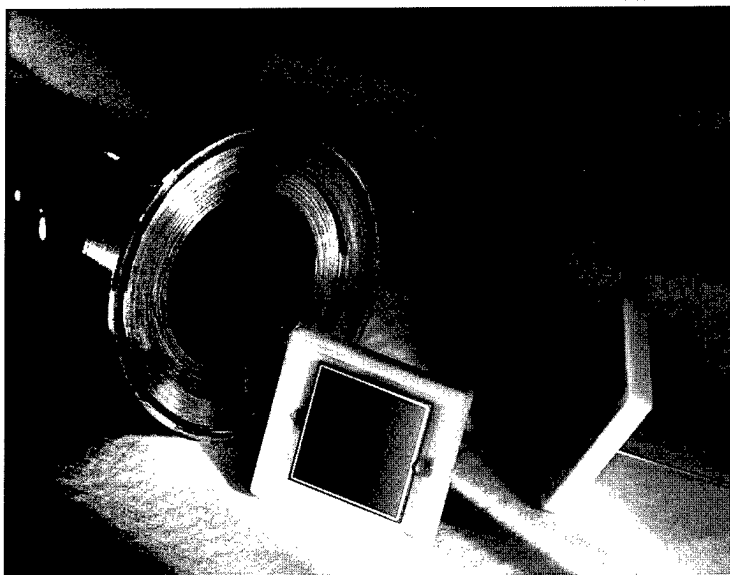
BMDO originally funded this technology for its Brilliant Eyes program. The National Aeronautics and Space Administration has also provided funding for space-based sensor cooling.

Current gas-fueled sorption compressors are not efficient enough to compete with their electrical counterparts—mechanical compressors—in heating and cooling buildings. But JPL's heat recovery technology, the regenerative sorption compressor system, has improved the efficiency. Using waste heat from one refrigeration cycle to heat a second compressor, the design employs a four-bed system, in which a thermal wave front passes waste heat from compressor to compressor.

Sorption compressors use a solid material (in this case, activated carbon) to physically adsorb (or chemically absorb) a low-temperature, low-pressure refrigerant. The sorbent is then heated, causing it to release the refrigerant at a higher temperature and pressure. When this high-pressure refrigerant is recooled and then expanded to a lower pressure, it provides low-temperature cooling. (The cycle can be reversed to provide heating.) JPL developed a carbon binding technique that increases the thermal conductivity of the sorption compressor by molding the carbon sorbent to aluminum fins. High thermal conductivity allows the thermal wave front to quickly cycle through the entire four-bed system. This quick cycling, in turn, allows the sorption refrigerator to provide high cooling rates with little sorbent material.



■ **Jet Propulsion Laboratory's** sorption compressor, which BMDO funded to cool space-based Brilliant Eyes sensors, not only could reduce heating and cooling bills for homes and businesses, but could also provide essentially free domestic hot water.



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Information Superhighway

As a high-priority initiative under the current administration, the foundation for the National Information Infrastructure, often referred to as the information superhighway, is currently being designed. This well-publicized visionary system is an interconnection of computer networks, telecommunications services, and software applications that will enable fast and efficient information accessibility and transfer on a national level to improve the quality of life, increase productivity, and improve the quality of products produced in both the public and private sectors.

Some of the areas currently being reviewed for the information superhighway are manufacturing, electronic commerce, health care, education and lifelong learning, environmental monitoring, libraries, and government services. For example, electronic commerce would enable distributed companies throughout the nation to rapidly, flexibly, and securely exchange and use information to drive their business processes. Potential capabilities include electronic funds transfer, government regulatory data interchanges, collaborative engineering, enterprise integration, and computer-supported collaborative work. There are several areas where new technology will be required—one being innovations to handle and allow users to sort through the flood of data from diverse sources in a timely, reliable, and effective manner.

Through the Small Business Innovation Research (SBIR), Innovative Science and Technology (IS&T), and other programs, BMDO has made significant contributions to the nation's technology base in the areas of photonics, superconductivity, and data-processing algorithms. BMDO's R&D efforts have produced several innovations in advanced communications that could be used to handle not only the flood of data during a ballistic missile attack, but also the flood of data that will be delivered over an immense system that touches every town from San Diego, California to the upper tip of Maine. The following section describes five small businesses (half of which are now public) that have or will soon have products or systems available in areas such as optical and satellite communications.

Information about the National Information Infrastructure was obtained from the National Institute of Standards and Technology's *Putting the Information Infrastructure to Work: Report of the Information Infrastructure Task Force Committee on Applications and Technology* (1994).

New Products Improve Fiber Optics

With advanced technologies in fiber-optic communications, Physical Optics Corporation has generated over \$2 million in commercial sales and has five BMDO-related products on the market.

Among the leaders in the photonics industry, Physical Optics Corporation, or POC, (Torrance, CA) has developed unique technologies in holography, multimedia communications, and monitoring instrumentation. This company has generated over \$2 million in commercial sales and has five BMDO-related products on the market. The BMDO SBIR program has contributed to the company's commercialization success, providing the technical base POC needed to acquire \$2.6 million in venture capital and over \$2 million in banking credit and equipment leasing lines.

Some of POC's BMDO-funded research has been in polymer microstructure waveguides that transport and direct optical signals. Research in this area has led to two communications- and computer-related products, listed below.

■ **Parallel communications systems.** Offering solutions for high-bandwidth communications systems, POC is marketing a BMDO-derived product that allows multiple optical signals to operate in parallel on flexible cable. Called the

active wavelength division multiplexer (WDM), this simple and economical device is used with commercially available laser diodes to increase the communications bandwidth and the number of channels passing through optical fibers. In addition, active WDMs, when serving as part of optical backplane buses, can greatly increase

the speed of computers and processors—the original application funded by the BMDO SBIR program.

According to some market analysts, very high-speed parallel communications systems will be one of the key ingredients in the future information superhighway, which will require that millions of communications channels be provided to every user. Active WDMs may also be important in year-2000 highly parallel computer systems for performing sophisticated operations such as near real-time weather prediction and design of high-performance hypersonic aircraft.

Active WDMs allow users to transmit multiple input signals in one or both directions without interference or crosstalk. POC's active WDMs are compatible with most multimode fiber systems and are available in standard configurations of two, three, or four channels.

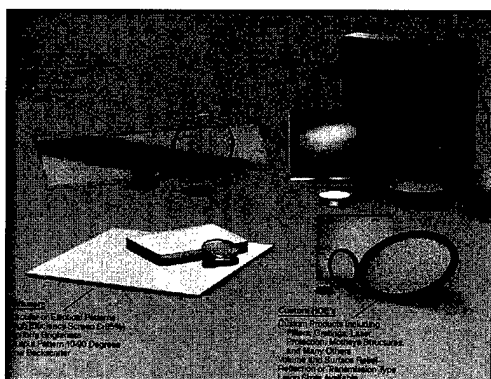
■ **Video transmission and multimedia communications.** POC has also recently introduced compact devices for fiber-optic transmission called FiberView links. These devices can be used to transmit video signals within local area networks. They can also be used for multimedia communications, interactive communications and teleconferencing. FiberView links provide a transmission bandwidth of 10 megahertz and a signal-to-noise ratio of over 56 decibels.

ABOUT THE TECHNOLOGY

Polymer waveguides offer advantages over other optical waveguides in solid-state microelectronics because the gel polymer layer is pliable and can be applied to flexible substrates such as ribbon, sheeting, and cable. They are also simpler and cheaper to make than conventional waveguides and can affordably be made larger. In addition, polymers have much higher inherent optoelectronic transmission bandwidth than glass or semiconductors—a quality that can be valuable for high-speed optoelectronic signal processing.

POC developed a graded-index (GRIN) polymer microstructure waveguide that transports and directs optical signals for many optoelectronic uses. The waveguide is made from a surface-applied gel polymer layer. This layer is treated to produce a graded optical index, which traps light in the polymer layer. Layers can be applied on smooth surfaces of many different substrate materials, including silicon, gallium arsenide, glass, lithium niobate, metals, and many ceramics.

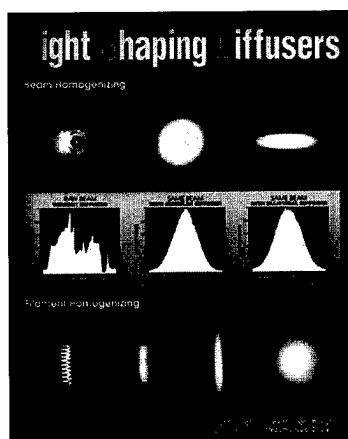
continued on page 55



■ Items pictured above are graphic products—filters, diffusers, diffraction gratings, and custom holographic optical elements—that can provide clearer images for environmental, biomedical, and entertainment applications.

continued from page 54

On the market, Physical Optics Corporation's Light Shaping Diffusers brighten and give higher contrast for flat-panel displays and high-definition television.



■ **Physical Optics' Light Shaping Diffusers** can eliminate hot spots from light sources and shape the light beam to match the area to be illuminated—important capabilities in many medical and scientific applications.

With the help of four BMDO SBIR contracts, POC also has holographic products on the market that can improve the quality of video images and fiber-optic communications and provide clearer images for environmental and biomedical imaging.

■ **Brighter, clearer images.** Imagine being able to watch a movie at a drive-in theater during the day. Holographic beam homogenizers, marketed under the trade name Light Shaping Diffusers, can make movie screens bright enough to be seen in daylight. They also have similar applications for flat-panel displays and high-definition television, brightening and giving higher contrast to these screens. In addition, Light Shaping Diffusers can be used to read documents and can improve the capabilities of spectroscopy, robotic vision, endoscopy, and LED (light emitting diode) display

illumination. The National Institute of Standards and Technology, through the Advanced Technology Program, is assisting POC in scaling up manufacturing of this technology to meet the high-volume screen applications. Individual filters currently cost \$80 to \$145, and kit prices range from \$275 to \$475, depending on the application.

Light Shaping Diffusers work by controlling the scatter of light in a limited solid angle, which can be either circular or elliptical. By homogenizing the light illumination, they eliminate "hot spots"—an important capability in Raman and fluorescent imaging. Beam shaping, in turn, allows excellent matching between the light source and the area to be illuminated.

■ **Light splitting for fiber optics.** POC is also marketing Bragg gratings for scientific and imaging applications. These devices can efficiently split light into different spectra and reduce scattering noise in both reflective and transmissive optics. Initially developed for optical communications and computing, they also can be used in fiber-optic communications, fiber-optic sensors, and spectroscopy.

■ **Clearer images for spectroscopy.** Offered by POC worldwide through a marketing representative, Raman filters offer the medical, environmental, and industrial communities clearer images when analyzing objects and materials. These devices effectively filter the desired spectral bandwidth for spectroscopic measurements. BMDO initially funded Raman filters to protect space-based sensors from ultraviolet light; however, they were first used commercially for Raman spectroscopy (hence their name). This technique determines the chemical composition of materials using a single-frequency laser beam. The filters can also be used for fluorescence spectroscopy, confocal microscopy, and beam splitting.

Raman filters transmit only the desired spectral bandwidth for spectroscopic measurements and prevent all other frequencies from disturbing the experiment. The filters have optical density cutoffs of about 6 and exhibit transition zones as low as 200 wavenumbers to the 70-percent transmission point standard.

ABOUT THE TECHNOLOGY

Holography is a way to store and produce 3-dimensional images by recording the interference pattern created when a laser beam illuminates an object. To create the interference pattern, light reflected from the object must interact with the original light wave so that the crests and troughs of the original light wave cancel or add to the crests and troughs of light waves returning from the object.

While holograms are most commonly associated with artistic uses, diffraction gratings recorded as holograms can serve as optical components including mirrors, lenses, filters, and splitters that are free of ghosts. They also exhibit very low levels of scattered light. And since they can be produced on thin substrates, they weigh less than traditional optics. In addition to the products described above, POC is working on other developments, such as gratings that serve as optical interconnections and modulate light waves for signal processing.

International Communications System Uses BMDO Technology

In a joint venture with a major U.S. corporation, Glynn Scientific is incorporating BMDO technology into a new Russian communications system.

From satellite-based communications systems to fingerprint identification for credit cards, Glynn Scientific, Inc., (Annapolis, MD) is finding an abundance of applications for its BMDO-funded technologies. Until 4 years ago, all of the company's work was on military R&D projects, primarily as a subcontractor to large defense companies such as Martin Marietta. Now, half of Glynn's business is commercial.

Currently conducting research for BMDO's Arrow and CorpSam projects, Glynn Scientific has spun off developments in radar and data-processing algorithms for a wide range of applications. This small, 14-employee business has focused on a diversified strategy to commercialize its inventions through its commercialization subsidiary, Glynn Technology Corporation.

As a result, Glynn Scientific has teamed with several large U.S. companies to develop new commercial products, including an innovative satellite-based communications system, a new very high resolution ultrasound machine, and an aviation landing system. For example, in one joint venture, the company's technology has been adapted for a new Russian communications system. Glynn Scientific's large-scale

teaming agreements presently account for about 30 percent of its business, a figure expected to double each year for the next few years with a payoff in the tens of millions of dollars within 5 years.

For fast and firm financial advice, Glynn Scientific has also incorporated artificial-intelli-

gence-based techniques into a product called MINRISK. This tool can help users optimally invest and provides additional techniques to reduce overall financial risks. Expected to be on the market in late 1994, MINRISK will be developed into PC-based products, direct services, and, potentially, investment organizations.

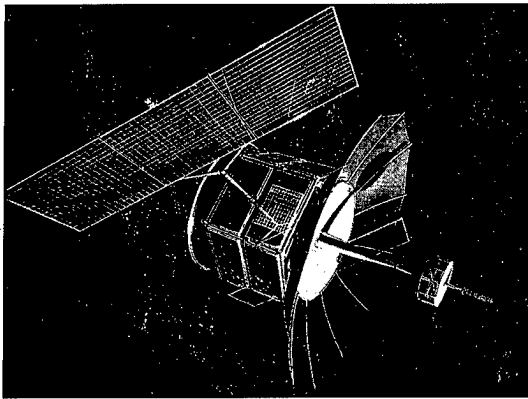
Some smaller inventions—such as ground-penetrating radar systems (to find storage tanks, etc.), anticollision sensors for automobiles, radar transponders for the marine industry, and fingerprint identification systems for credit cards—are also being pursued. Glynn Scientific will market these products through a specialty marketing group.

In addition, Glynn Scientific is investigating the marketing possibilities for electromagnetic field detectors for homes and a device attached to the car antenna that protects cellular telephone users from adverse health effects related to electromagnetic fields. The company has several patents on its radar and data-processing algorithms.

ABOUT THE TECHNOLOGY

One of the technologies that Glynn Scientific developed for BMDO was convolution ambiguity multiple access (CAMA). Invented by Glynn Scientific and further developed on a BMDO-funded program, CorpSam, this new technique for multiplexed microwave communications signals solves time-shift and frequency-shift problems. The use of CAMA allows for higher capacity in much smaller satellite terminals, reducing the cost of terminals to below \$5,000. For instance, Glynn Scientific researchers can get 6,000 simultaneous channels in 36 megahertz while only using a 1-meter dish. In addition, CAMA has a low susceptibility to doppler, and terrestrial and adjacent satellite interference.

Other BMDO-funded technologies that Glynn Scientific invented include the noise-light continuous wave, which is a fast signal-processing algorithm for radar returns, and 2-dimensional autocorrelation, which is a target identification technique that yields very high identification performance from distorted data.



■ Convolution ambiguity multiple access (CAMA) allows for higher capacity in much smaller satellite terminals.

Bright Future Is Forecast For Avalanche Photodiodes

Advanced Photonix, traded on the American Stock Exchange, now manufactures and sells four new products for optical communications, optical computing, medical imaging, and experimental physics.

Researchers at Advanced Photonix, Inc., (Camarillo, CA) have been busily breaking new ground, selling large-area silicon avalanche photodiodes (APDs)—devices that can greatly improve the performance of optical equipment.

APDs can be used to detect and amplify light for applications such as optical communications, optical computing, experimental physics, and medical imaging. They are among the first solid-state devices to rival photomultiplier tubes (PMTs) in gain, noise, and surface area. By replacing PMTs, APDs bring the same qualities of ruggedness and low cost for detecting and amplifying electromagnetic radiation that other semiconductors have brought to the rest of the electronics industry.

These solid-state photodetectors can detect and amplify electromagnetic radiation in all visible wavelengths, as well as some ultraviolet and infrared wavelengths. They can also directly

detect x-rays and charged particles, and when coupled to scintillating crystals or fibers, they can detect gamma rays.

With a 40,000-square-foot manufacturing facility, Advanced Photonix now produces custom-designed APDs and standard packages with diameters of 5, 10, 16, and 18 millimeters.

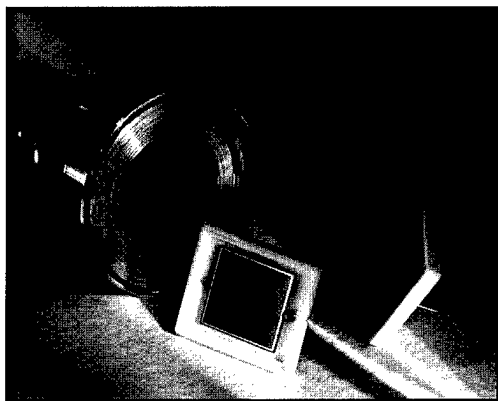
The 18-millimeter-diameter APDs are vacuum-enclosed, which means they can detect individual photons and ultralow levels of electromagnetic radiation.

Xsirius, Inc., started this publicly owned company in 1988 to design and manufacture silicon APDs. In 1991 and 1992, Advanced Photonix acquired the assets of two leading photosensor companies—Silicon Detector Corporation and Advanced Optoelectronics. The BMDO SBIR program originally funded early research on APD technology at Xsirius in the late 1980s to detect missiles; the program later funded research at Advanced Photonix.

ABOUT THE TECHNOLOGY

When photons, x-rays, or charged particles hit the surface of an APD, the detector produces an electron-hole pair (a hole is a positive charge carrier). If a voltage difference is applied between a cathode and an anode, the holes travel toward the cathode while the electrons travel toward the anode. To reach the anode, however, electrons must pass through the avalanche region. As an electron passes through this region, it creates new electron-hole pairs, each member of which also flows toward the cathode or anode. As they travel, these pairs produce even more electron-hole pairs, thereby amplifying the original signal. Because a greater voltage difference encourages more electron-hole pairs to form in the avalanche region, the output signal can be raised or lowered by changing the voltage difference.

But APDs can only amplify a signal up to a certain point. When the voltage difference reaches the breakdown voltage, high noise levels make detection difficult. In conventional APDs, the breakdown voltage is so low that they can only operate in Geiger mode, in which the applied voltage is reset whenever it passes the breakdown voltage. Because of high noise, Geiger-mode operation does not allow APDs to read the number of incident photons that originally hit them. Without this information, APDs cannot be used to determine the energy levels of the incident radiation and do not provide high dynamic range. Advanced Photonix's APDs, however, have a breakdown voltage high enough to operate in the linear mode, where the applied voltage does not need to be continually reset. The ability to operate in the linear mode gives Advanced Photonix's APDs considerably more versatility than other devices.



■ Advanced Photonix's avalanche photodiodes are among the first solid-state devices to rival photomultiplier tubes in performance, making them useful in areas ranging from optical computing and communications to medical and scientific imaging.

Superconducting Shift Register Remembers For Readouts

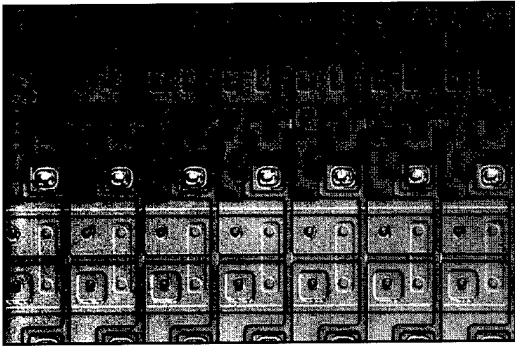
Conductus, a BMDO-SBIR-funded company that went public in 1993, is leading an Advanced Technology Program award to develop superconducting Josephson signal processors—using BMDO-funded R&D.

Conductus (Sunnyvale, CA) is developing a superconducting device called the shift register that works 10 times faster than state-of-the-art silicon chips. Enabling speedier communication and computers, this superconducting alternative to random access memory (RAM) could significantly lower power needs while allowing superconducting and conventional electronics to be used together.

BMDO has partially funded Conductus' effort through an SBIR contract to improve wideband communications and radar, but the company is also looking at other applications. For example, Josephson junction shift registers could significantly improve rates for data transmission and lower power requirements for gigabit fiber-optic communications and 3-dimensional computer-aided image reconstruction.

These shift registers could also be used in superconducting digital signal processors, which are projected to have clock speeds as high as 10 gigahertz. With such high speeds, these devices would allow 3-dimensional images to be reconstructed in seconds.

The company received a Department of Commerce Advanced Technology Program award to develop a low-temperature Josephson



■ In one research project, simulations of the shift register (pictured above) showed that shifts between cells could be as fast as 5 picoseconds.

signal processor using an alternative to RAM called a first-in first-out (FIFO) device. The superconducting shift register, developed under BMDO funding, is expected to be central to the FIFO device. Conductus is the prime contractor with Hewlett-Packard, TRW, the University of

California at Berkeley, Stanford, and the National Institute of Standards and Technology (Boulder, CO) as subcontractors.

To measure the characteristics of the superconducting shift registers, Conductus has also built a new testing facility for superconducting circuits. This facility allows researchers to design and assemble custom electronics and develop a novel sample holder that holds the

chip as it cools and facilitates good electrical contact. The superconducting shift register is expected to be incorporated into Conductus' product line in 1 to 4 years.

ABOUT THE TECHNOLOGY

Josephson junctions are fast but forgetful—these superconducting versions of the transistor do not store data very well. Despite their near-perfect energy efficiency, Josephson junctions cannot provide short-term memory storage for data readouts, especially when interfacing with conventional semiconductor circuits. Conductus is increasing the compatibility of superconducting and conventional digital electronics with its superconducting shift register. These shift registers can sequentially record and retrieve data bits, storing messages long enough for the slower semiconductor circuits to receive them.

Conductus' 32-bit superconducting memory works 10 times faster than state-of-the-art silicon chips. Operating at 120 gigahertz, the internal clock performs at least 2,000 times faster than those in the most advanced personal computers, according to tests. In one research project, simulations showed that shifts between cells could be as fast as 5 picoseconds.

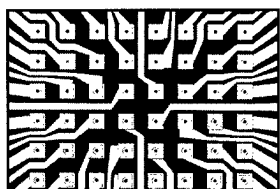
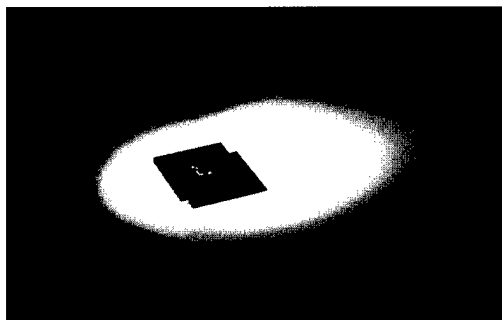
Conductus has developed three prototype superconducting shift registers: one made of niobium, one made of niobium nitride, and one made of yttrium barium copper oxide (YBCO). Niobium and niobium nitride materials are low-temperature superconductors, which require liquid helium for cooling to operating temperatures below 10 kelvins.

On one project partially funded by BMDO, Conductus demonstrated a YBCO shift register using over 60 junctions, which makes it one of the largest integrated circuits demonstrated to date using YBCO Josephson technology.

BMDO funded the circuit design, and Sandia National Laboratories (Albuquerque, NM) and AT&T Bell Laboratories (Murray Hill, NJ) contributed research and expertise for fabrication.

Laser Arrays To Revolutionize Communications, Computers

With manufacturing facilities and a product on the market, Photonics Research, Inc.'s LASEARRAY™ technology could be ideal for fiber-optic cables.



■ PRI's LASEARRAY™ technology is about 100 times smaller than edge-emitting diode lasers, so it can be easily stacked side by side in 1- and 2-dimensional arrays.

Photonics Research, Inc., or PRI, (Longmont, CO) has pioneered the development of a key component in replacing microelectronic signals with optical signals. Targeting fiber-optic, computer, and medical imaging markets, PRI is manufacturing the first vertical cavity surface emitting laser (VCSEL) under the trade name LASEARRAY™.

LASEARRAY™ technology could be ideal for fiber-optic cables. Researchers have demonstrated extremely high efficiencies (over 90 percent) in coupling fiber optics and VCSELs. And since VCSELs can operate over multiple channels, they can simultaneously send hundreds of different-wavelength signals down a fiber-optic cable, accessing its full bandwidth potential. In the near term, they can be used between buildings, computers, and circuit boards for short-haul fiber optic interconnections. For long-distance fiber-optic communications, researchers are looking for ways to make VCSELs that work in the visible region—where fiber-optic transmission is most efficient.

PRI's product can also replace many of today's low-data-rate computer products with faster, multichannel devices. For example, these devices could be used in multichannel optical data storage systems, high-definition projection displays, and digital printers. VCSELs can be integrated with light detectors and logic circuits to produce optoelectronic devices that perform logic operations. Known as smart pixels, the logic devices could be used in both digital and neural optical computers. LASEARRAY™ technology could also be used for solid-state barcode scanners.

In addition, these devices could be used for medical imaging applications. PRI is working with the Eye Research Institute to develop a confocal microscope using its product for medical imaging. Confocal microscopy is a 3-dimensional imaging technique used in biological sectioning. The technique is also used for inspecting semiconductors.

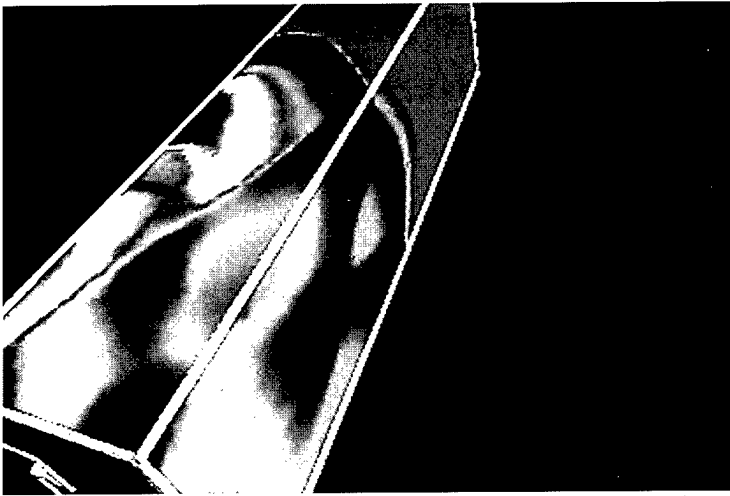
With three patents on VCSEL technology and seven more filed, PRI has formed over 20 alliances with other organizations to further develop VCSEL technology and introduce new products using LASEARRAY™ technology. PRI also offers custom fabrication and packaging of micro-optics, serial and parallel laser driver circuits, optoelectronic and electronic molecular beam epitaxy materials, detector arrays, and optoelectronic components.

The BMDO SBIR program helped much of PRI's R&D in this area for optical signal processing, optical data storage, and fiber-optic communications systems. PRI has also received government support for this research from the Army, Air Force, Advanced Research Projects Agency, Navy, National Science Foundation, National Institutes of Health, and National Aeronautics and Space Administration.

ABOUT THE TECHNOLOGY

Vertical cavity surface emitting lasers, or VCSELs, are so named because they emit laser beams perpendicular to their surface, unlike other diode lasers, which emit light from their edges. VCSELs are about 100 times smaller than edge-emitting diode lasers and can be easily stacked side by side in 1- and 2-dimensional arrays. They also produce nearly circular beams that diverge considerably less than those of edge emitters and therefore require less sophisticated optics to focus the beam.

VCSELs have not been used widely because of problems in developing mass production techniques and the relative inefficiency of VCSELs when compared with traditional lasers. PRI has lowered these barriers by building a manufacturing facility and modifying VCSEL design to provide efficiencies similar to those of diode lasers. This advance has resulted in smaller, higher-power lasers with extremely fast switching speeds (which allow high-speed data transmission).



*Parasoft
Corporation,
page 67*

Software

The software industry is one of the fastest-growing segments of the computer industry, employing nearly 139,000 workers at the end of 1992, a 12-percent increase from the approximately 124,000 workers at the end of 1991. During those same years, revenues for the packaged software market grew 13 percent (from \$52.5 billion to \$59.4 billion); they are expected to climb to \$100 billion by 1996. U.S. vendors account for about 75 percent of the world software market.

With a wide spectrum of applications ranging from complex heavy industrial processes to first-grade education programs, software development allows companies to break into markets that might be otherwise unapproachable. But software development can also be a fast-paced area where the latest developments soon become outmoded by somebody else's tools. Advanced computer technology—now moving toward optical computers—is further emphasizing this pace.

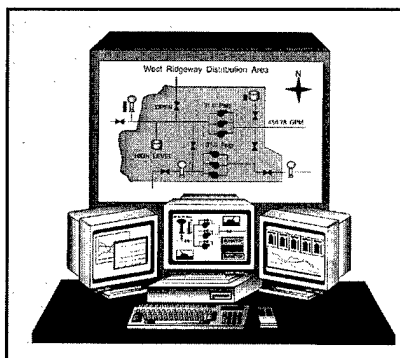
Other issues relate more specifically to defense-oriented software. For example, some BMDO-funded companies have noted that trying to sell artificial intelligence software commercially under the name "artificial intelligence software" is usually not an effective marketing approach. The diversity of potential market areas and the associated requirements for customization present numerous challenges. In this area, developers can be shortchanged if they simply state broad performance capabilities without targeting specific requirements; only after identifying an individual need can software developers provide a quality product, often customizing solutions that are usable only for that particular application.

BMDO has funded the development of highly sophisticated (and highly commercializable) software in areas such as parallel processing, automation and control, and software development tools. Understanding the challenges of such a dynamic and diverse market, developers of this software have successfully converted their products to commercial uses. The following section describes over 10 new products currently addressing needs such as real-time capabilities and application diversity in areas such as gas and oil production, municipal water supplies, and intelligent vehicle highway systems.

Information obtained from Standard & Poor's Industry Surveys, October 7, 1993.

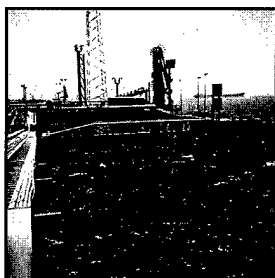
Oil Producers, Municipalities Use Real-Time Software

Both domestically and abroad, Tate Integrated Systems has sold TIS 4000® to monitor and control processes for municipal water treatment and oil production.



■ Above: This illustration depicts a workstation for the TIS 4000® system.

Below: Among other applications, the TIS 4000® can be used to monitor and control oil production.



From producing oil to treating drinking water, Tate Integrated Systems' (Owings Mills, MD) computer-based system called TIS 4000® is being sold to industries and governments to monitor and control complex processes. At the heart of this system is software developed for a BMDO-funded accelerator.

Tate is already selling an enhanced version, with 15 projects under way and annual sales exceeding \$3.7 million. Starting at \$50,000, the TIS 4000® now monitors and controls offshore oil production for ARAMCO, as well as water treatment processes for St. Louis County, MO. In addition, Baltimore Gas and Electric is using Tate's system for its liquid natural gas terminal.

Tate has primarily been approaching the gas and oil production industries with this product. As an illustration of this market's size, the United States alone spent over \$287 billion for petroleum and natural gas in 1991². The TIS 4000® can automate production and monitor and control oil pipelines, gas pipelines, terminals, and tank farms. It can detect tank leaks and track and control oil and gas being moved by ship, train, or truck to and from pipelines.

The TIS 4000® can also be used in oil fields to monitor and control high-pressure wells. Applicable for both onshore and offshore operations, it can operate in remote locations lacking communications or electricity. And since the TIS 4000® uses off-the-shelf computer equipment and has a relatively low cost, it is especially attractive to municipalities for water and wastewater management.

With this system, users can graphically model and then monitor and control specific processes. For example, with the graphics package, users can create a model of the water treatment facility, linking important parameters—such as water flow data—to objects such as meters. This flexible and comprehensive family of hardware and software is based on an open architecture and provides real-time and historical data in user-friendly windows.

Tate licensed the software from Los Alamos and Argonne National Laboratories. The original software, called the Experimental Physics and Industrial Control System (EPICS), was developed with BMDO funding to provide control and data acquisition for the ground test accelerator. Other parties involved in the coexclusive licensing agreement are mentioned on page 63.

ABOUT THE TECHNOLOGY

The TIS 4000® can be connected to a local area network (LAN) and a wide area network (WAN) at the same time. The standard system runs on commercially available workstations and can be bridged to PCs with minimal software modifications. All hardware is off-the-shelf, and equipment from multiple vendors can be used. Since a very basic TIS 4000® system requires only a few building blocks (workstations, a LAN gateway, and remote terminal units or a process control unit), its size is flexible.

A notable feature of TIS 4000® is the man-machine interface (MMI). Through graphics, trend lines, and text, users can see what is happening in their processes in real time. MMI allows object-oriented graphics to be parameterized. Features of the MMI include the following:

- **Full-color graphics editor** to make custom display pages;
- **Set of "trend windows"** to pull and plot real-time and historical data values;
- **"Database access window,"** which is a graphical object library to control databases;
- **Alarm manager** to alert the operator when alarms are detected;
- **Flexible report generation package** with Lotus 1-2-3™ report generator and dBASE IV™ database access library; and
- **State-notation-language compiler.**

²Latest available data from the Energy Information Administration.

Real-Time Software Becomes Reality For Industries

KineticSystems

Corporation's new software, Reality™, can control a wide range of applications such as manufacturing and robotics.

As the old saying goes, a picture is worth a thousand words. KineticSystems Corporation (Lockport, IL) and Titan Corporation (Albuquerque, NM) are taking this advice, marketing their software in the industrial and scientific communities.

With this software, users can picture what is going on in their processes in real time because they can create and link object-oriented graphics. For example, users can link temperature with the picture of an engine and then monitor and control that specific parameter.

KineticSystems and Titan licensed the software from Argonne and Los Alamos National Laboratories, or ANL and LANL, in a coexclusive agreement. From aircraft engines to haz-

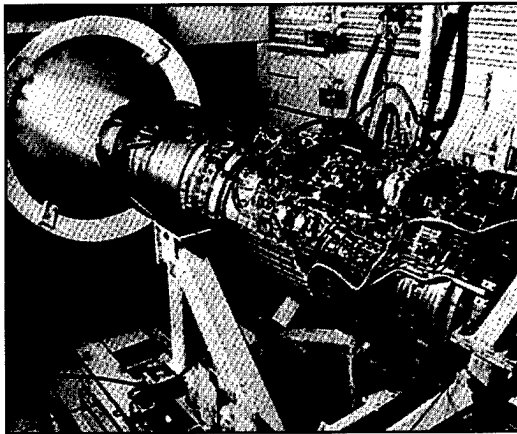
ardous waste, these two companies are now marketing an enhanced version of the software to a wide variety of users.

For example, KineticSystems' new version of the software, called Reality™, can be used to monitor and control robots that handle hazardous materials and to control processes for manufacturing and pro-

duction. And for uses such as monitoring the performance of jet engines, KineticSystems is modifying the system for discrete process control applications.

The company's software is also being marketed for quality control processes, test stands for a variety of products, and scientific and industrial research. In addition, KineticSystems is enhancing the Reality™ software package to support high-speed fiber-optic serial data highways with many input/output controllers (IOCs) in remote locations.

Currently pursuing third parties to distribute the software, Titan expects to have a commercial product ready in 6 months, approaching the same markets as KineticSystems. The two companies expect to share various aspects of the software, including documentation.



■ Reality™ can be used to monitor jet engines that are being tested. Jet engines must endure rigorous diagnostic tests analyzing the effects of such factors as pressure, temperature, and strain over long periods.

The companies' products are based on software called the Experimental Physics and Industrial Control System (EPICS), which BMDO funded at LANL and ANL to monitor and control a particle beam accelerator.

ABOUT THE TECHNOLOGY

This system can efficiently support many IOCs for small, medium, and large systems. The software has an open architecture, which allows the system to be used on many types of hardware—even PCs. Supporting a large number of IOCs, it currently uses Unix®-based workstations. Components of this system include the applications programs, run-time environments, IOC software, databases, channel access, and an alarm handler. The applications programs are particularly notable and are described below:

■ The **Operator Interface** graphically interfaces with the IOCs. Through graphical windows, users can design display icons, such as meters, switches, connectors, and strip charts, and attach them to parameters.

■ The **Alarm Handler** can monitor an entire system. The operator can create a hierarchical system monitor based on alarm conditions or warnings defined in the database.

■ The **Sequencer** allows the user to develop control tasks by creating simple or complex algorithms for data acquisition and control at the workstation. The Sequencer attaches algorithms to the database.

■ The **Historian** allows users to collect and review specific data during a data acquisition and control run for later analysis.

■ The **Channel Access Development Library** allows users to create workstation-level programs that interact directly with the IOCs.

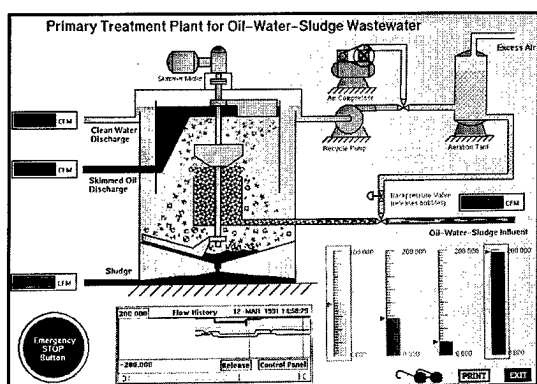
From Engine Testing To Power Monitoring, Software Takes Control

Vista Control Systems has sold over \$1 million in process control software and related hardware for power plants, avionics, and transportation systems.

Vista Control Systems (Los Alamos, NM) is answering the million-dollar question of how to commercialize defense technology with its new Vsystem software package, now available in the commercial marketplace. While the software was originally intended for controlling particle beams in space, its proven-to-be-profitable applications here on earth are for controlling industrial processes and other applications.

The Vsystem software package is a set of tools that allows users to graphically build and monitor control systems. The package can graphically present information to show the status of the system and give the user control of the system.

In 1989, Vista Control Systems evolved from Los Alamos National Laboratory, or LANL, and licensed software that was developed at the



■ A wastewater control screen, pictured above, uses Vsystem control tools to monitor and control the flow rates of the process.

laboratory to control particle beams in BMDO's Neutral Particle Beam Accelerator. In this project, an expanding telescope constructed at LANL was installed at Argonne National Laboratory to produce a low-divergence negative hydrogen ion beam. Part of this

requirement was a telescope control system. Vista Control Systems enhanced the software, making it available in the commercial marketplace.

Five years later, Vista Control Systems has attracted dozens of customers who are using the software for a wide spectrum of applications, such as testing aircraft engines, monitoring nuclear power stations, and testing transmissions. The software has also been used for power distribution and water quality control. Vista sells more than half its software packages, which start at around \$15,000, to commercial businesses both in the United States and abroad. Software for noncommercial uses is sold primarily to the U.S. Department of Energy.

ABOUT THE TECHNOLOGY

This software combines a graphics package with a networked, open, real-time database. By combining these two components, users can create and modify control displays and link them to the Vsystem real-time database without programming. Databases can run alone or in a distributed environment, and single or multiple input/output (I/O) subsystems may be used. Vsystem can be operated from Open VMS™, ELN™, and Unix® platforms. A Vsystem toolkit includes several features:

■ **Vaccess** is central to Vsystem. This real-time database and library of access routines maintains all information about the state and control of a project.

■ **Vscan** actively connects the I/O hardware with the Vsystem real-time database.

■ **Vdraw** allows users to design data acquisition and control screens that automatically connect to Vaccess. Under Xwindows, Vdraw has a toolbox to draw control screens. This graphics feature informs users about the state of the real-time database and allows them to control various processes.

■ **Vlogger** logs data from the Vsystem database and produces a standard output file. It also conducts what-if studies by letting users play back all or part of a log file that is stored in a real-time database.

■ **Vtrend** is a history and trending application for viewing logged data. In Vtrend, users can select start and stop times for viewing the data.

■ **Vscript** eliminates the need for conventional programming when manipulating the database.

■ **Valarm** is an interactive alarm module that can display and record alarm messages.

Expert System Knows Smart Highway

On the road to commercialization: From controlling satellites to traffic lights, Interface & Control Systems, Inc.'s software makes expert decisions for space and terrestrial applications.

As the first expert system used in space, Spacecraft Command Language (SCL) monitors and maintains the health of a system using a new programming language originally designed for spacecraft command and control. This software—developed by Interface & Control Systems, Inc., or ICS, (Melbourne, FL)—enables systems such as spacecraft and traffic signal patterns to react with flexibility to new or unforeseen situations.

The SCL system was first flown aboard BMDO's Clementine space probe. Clementine's trek through space required a high degree of autonomy, and the probe relied on SCL to monitor its health and resolve any anomalies. The rule-based software also reacted to incoming telemetry, verified commands sent from ground stations, and executed them.

But ICS is also using SCL to gather information about a city's traffic conditions and adjust the signal patterns of its traffic lights. Other partici-

pants designing this "smart highway" system include a graphics company and a digital mapping company.

ICS's expert system has also been used to monitor fiber-optic communications equipment in Kennedy Space Center equipment racks. In addition, the company is using SCL to maintain the health of a

materials-processing experiment on board the space shuttle and to control an experimental docking and rendezvous satellite.

The SCL language reduces the need for specialized programmers. Users can program with traditional commands and add expert system rules as they become more comfortable with the software. System developers or testers use a window environment to develop scripts and rules.

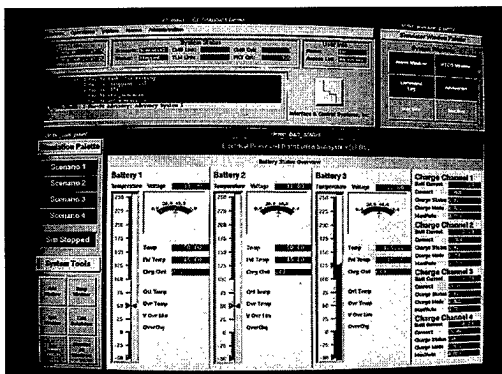
SCL also reduces costs, time, and labor required for spacecraft software by operating in every phase of a spacecraft's existence. For example, it can be used in preflight development and test workstations, the onboard

processor, and the ground-based controllers. Using one software package rather than different software in each processor reduces costs by eliminating redundant training and programming. It also increases reliability by avoiding hidden incompatibilities between software packages.

ABOUT THE TECHNOLOGY

SCL includes artificial intelligence technology along with time-based, procedural programming. Artificial intelligence technology can make decisions and modify the computers' actions without human intervention. SCL responds to events using code that monitors and controls communications and equipment. It accesses rules in the knowledge base that allow the computer to verify communications and operations and make operational decisions as necessary.

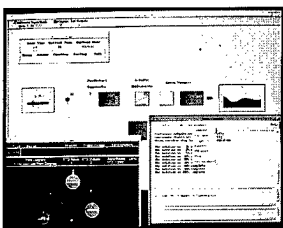
The heart of the SCL system, the Real-Time Engine (RTE), is a multitasking command interpreter compiled in Ada or C. The RTE is compact (about 64 kilobytes when compiled for the Motorola 680X0 family of processors) to ensure that it can be used in processors with a variety of memory sizes. Setting up the RTE in a processor requires low-level hardware interface code for the processor to access the system components. The SCL system also needs a database that describes digital and analog objects representing spacecraft sensors and actuators. A knowledge base defines the operating rules for the expert system using programming scripts and rules written in SCL. Scripts and rules operate independently or as subroutines, reducing the need to repeatedly program routines from scratch.



■ SCL includes artificial intelligence technology that can make decisions and modify the computers' actions without human intervention. The system responds to events using code that monitors and controls systems, such as an electrical power and distribution subsystem, as shown in the screen above.

Programming Tools Make Designing Software Easier

*Integrated Systems, Inc.'s
MATRIX_x[®] software
designed the DC-X's
guidance, navigation,
and control code at half
the cost and in two-thirds
the time of conventional,
hand-coded software.*



■ Integrated System's MATRIX_x[®] products—which are used for applications such as robotics and automotive systems—consist of a mathematical analysis package, a modeling and simulation tool, an automatic code generator, and a rapid prototyping system.

Integrated Systems, Inc., or ISI, (Santa Clara, CA) is selling a family of software products called MATRIX_x[®], which makes designing software faster, simpler, and cheaper than traditional processes. This product family gives users an automated way to design and generate programming code for control systems.

Using MATRIX_x[®], engineers at McDonnell Douglas estimated that they cut costs in half when designing the code for guidance, navigation, and control of the Delta Clipper Experiment (DC-X). And in this demonstration, engineers reduced development time by one-third from what would have been expected if

the reusable space launcher had used conventional, hand-coded software.

As a result of its time-saving, money-saving qualities, MATRIX_x[®] has significantly contributed to ISI's \$41.7 million annual revenues for fiscal year 1993. It consists of five software packages and is being targeted to a wide range of customers.

The largest commercial market for MATRIX_x[®] is in embedded controllers for automated teller machines, industrial process control, robotics, automobiles, and power plants. The aerospace industry can also use these design tools for flight control software for aircraft and

launch vehicles, satellite operations control, and system test beds.

ISI developed each of the MATRIX_x[®] design tools over 10 years. Two BMDO-funded projects, however, have provided high-level demonstrations of the company's software development methods. One was for the DC-X, as previously described. ISI's design tools were also used in the Miniature Sensor Technology Integration (MSTI) satellite program, where the tools improved productivity over traditional design methods by 300 percent. In this project, the software produced operational flight code for a space-qualified MIL STD 1750A PACE flight computer.

ABOUT THE TECHNOLOGY

In designing real-time software control systems (used, for example, in flight control of spacecraft), engineers must complete four steps. First, they must formulate a model of the system to be controlled, in this case a spacecraft. Second, they must design and evaluate a strategy for controlling the spacecraft's flight path. Third, they must produce a prototype controller. And fourth, they must integrate and test the prototype in a working model of the spacecraft. This process is by nature iterative—problems discovered in the third step often require designers to start all over again. ISI's product family has integrated this iterative process into a single task. MATRIX_x[®] products are described below:

■ **Xmath[™]** develops mathematical models of system and subsystem behaviors and control design.

■ **SystemBuild[™]** lets engineers quickly develop graphical models and animated simulations of the system to be controlled. Engineers can develop these models without the need for programming by selecting and connecting predefined blocks from a palette.

■ **AutoCode[™]** automatically generates real-time C or Ada programming code from SystemBuild[™] block diagrams.

■ **Document It[™]** automatically generates code documentation from SystemBuild[™] block diagrams.

■ **RealSim[™]** implements the models designed with SystemBuild[™] and compiles them with AutoCode[™] directly in hardware. As a result, RealSim[™] automates software development of real-time, embedded controllers.

Software Eases Transition To Faster Computers

With three related products annually producing up to \$1.7 million in sales, ParaSoft Corporation is finding a fast way to adapt conventional software to a parallel-processing environment.

ParaSoft Corporation (Pasadena, CA) has developed a processing tool called ASPAR that will adapt software written for serial computers to faster, more powerful parallel systems.

Currently, most computers are serial; they operate sequentially and perform only one task at a time. Computers using parallel processors, on the other hand, are much faster because they can perform many functions simultaneously. But the speedy parallel processors of tomorrow are not commonly used today, partly because almost all current software is specifically designed for serial computers. The software is not compatible with parallel processors, and users must write new software—a costly and time-consuming process. By automatically converting existing software to a form

that parallel computers can use, ParaSoft's ASPAR will save both time and money.

While ASPAR is still in the prototype stage, the company has been selling an average of about \$1.7 million annually in other software products originally developed through BMDO SBIR funding. For example, ParaSoft's software-adapting technology is commercially available through the Express software package, a parallel-processing toolkit that helps software engineers write programs for parallel computers.

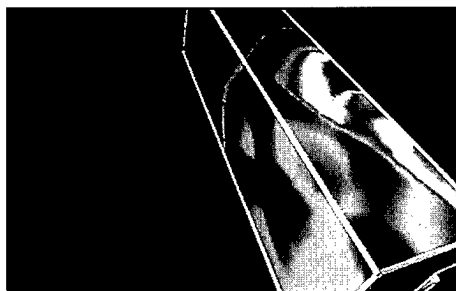
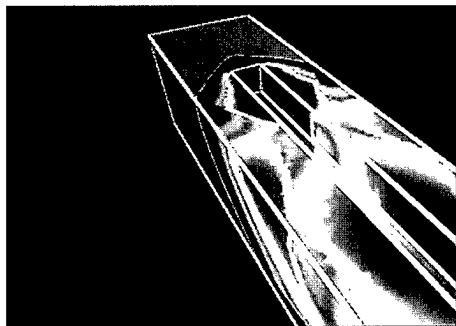
The company is also selling about 100 Insight™ packages a month; this software automatically detects programming bugs

in sequential software and reports them to the user. A module called Invision is included in the Insight™ package. It allows users to visualize the execution of programs. Most major software developers and several government agencies have purchased the Insight™ package, which currently supports the C and C++ languages. Versions for Microsoft® Windows™ and MS-DOS® are expected to be available soon.

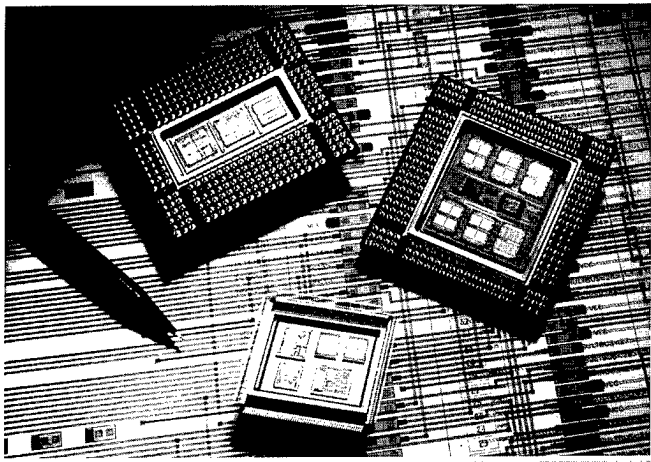
ParaSoft's ParSim, currently in the prototype stage, examines data for sequential applications and predicts its performance on multiprocessor systems. The company is also finding ways to save hours of programmers' time using software for automatic test case generation, which tests each statement in the source code of software that programmers are developing. The software can perform thorough and detailed data dependency and flow analysis of programs.

ABOUT THE TECHNOLOGY

ParaSoft has made several technical innovations through its BMDO-funded research on parallel-processing software. For example, the company has developed a process for data-dependency analysis that is extended beyond the state of the art. In this process, any pointer in the program can be traced with great precision. Also, the company has invented a "distribution processing" run-time with memory. This invention allows the parallelization process to be simplified; many decisions during the process are postponed until execution, when they can be run more efficiently. In addition, ParaSoft has developed a data partitioning and optimization algorithm that significantly improves the performance of programs.



■ ParaSoft's Exflow program, which runs under the Express software package, uses parallel processing to simulate fluid dynamics.



*nChip,
page 72*

Microelectronics

The microelectronics market share for U.S. firms is a once-waning, now-growing area characterized by fierce international competition. The U.S. share of the world market in semiconductors and microelectronics equipment plummeted from 80 percent in the 1980s to 45 percent, but much of this drop has been reversed. The United States captured about 53 percent of the world market in 1992, with the Japanese declining to 38 percent.

Based on projections of Integrated Circuit Engineering Corporation (Scottsdale, AZ), a market research firm, worldwide semiconductor sales are expected to nearly double from \$74 billion in 1992 to \$138 billion in 1997. International sales of microcomponents, including microprocessors, microcontrollers, peripheral digital signal-processing chips, and other electronic products, increased 17 percent in 1992 to \$13.5 billion, holding a 59-percent market share globally.

BMDO has funded numerous technologies in the microelectronics area that relate to semiconductors and microcomponents and their production. Funding of these state-of-the-art technologies from sources such as the SBIR program has resulted in millions of dollars in product sales, as well as a stronger defense.

Latest available information at the time of writing was obtained from Standard & Poor's June 1993 Industry Surveys.

R&D Leads To Flat-Panel Displays, Safer Chip Production

Advanced Technology Materials, Inc., which has recently gone public, is now collaborating with two partners to develop flat-panel displays using diamond technology developed with BMDO SBIR funding.



■ Pictured above is electron spectroscopy of one of ATMI's proprietary emitting materials inside the Ultrahigh Vacuum Surface Analysis and Electron Emission Chamber.

Advanced Technology Materials, Inc., or ATMI, (Danbury, CT) is commercializing a wide spectrum of products ranging from flat-panel displays to safer processes that produce better semiconductors—all with support from the BMDO SBIR program. As a leader in chemical vapor deposition (CVD) technology, ATMI has developed thin-film materials and production techniques for microelectronics. The company recently held an initial public offering to raise the capital needed to introduce new products to the marketplace and is participating in several joint ventures.

■ **Diamond cold cathodes for flat-panel displays.** With matchless mechanical, thermodynamic, optical, and electronic properties, diamond thin films may be the most important material that ATMI is developing. ATMI's work on CVD diamond thin films focuses on microelectronic uses.

Because they can serve as a source of electrons in field emission displays (FEDs), cold cathodes (devices that can emit electrons while consuming little power) provide the nearest-

term high-volume application of diamond microelectronics. This technology may pave the way for low-cost production of large-area flat-panel displays, a market estimated to be about \$6 billion. Diamond's unique electronic properties enable

diamond cold cathodes to emit electrons while using much less power than other materials. Therefore, diamond cold cathodes may have the brightness of active-matrix-liquid crystal displays while being as easy to manufacture as current FEDs.

ATMI recently received a \$1-million BMDO SBIR cost-shared contract to develop a prototype diamond cold cathode. In this contract, the company is collaborating with Silicon Video Corporation to develop flat-panel displays using diamond cold cathode technology.

ATMI, with technical assistance from the Massachusetts Institute of Technology's Lincoln Laboratory, will develop the diamond cathodes; Silicon Video will integrate the final flat-panel display. In the process of this work, ATMI has developed broad capabilities in thin-film diamond CVD, doping of diamond to convert it into a semiconductor, and interconnect technology to produce working electronic devices.

■ **Barium titanate thin films.** Using a metal-organic chemical vapor deposition (MOCVD) process, ATMI was the first group to grow thin films of barium titanate with controlled crystalline orientation. Since then, ATMI has become the world leader in CVD of barium titanate and barium strontium titanate thin films. These materials display many exceptional electronic and optoelectronic properties, such as permanent electrical polarization and the ability to store over 100 times more charge than silicon dioxide.

Through a BMDO SBIR contract, the base technology was funded to develop planar optical waveguides for optical switching, optical data processing, and photonic switching applications. (The National Science Foundation has also funded related work in this technology.) But ATMI is also looking at commercial applications, acknowledging the material's inherent qualities for producing ultrahigh-density dynamic random access memory (DRAM) devices. ATMI therefore entered into an agreement in August 1992 with IBM, Texas Instruments, and Micron Semiconductor to develop advanced thin-film capacitor materials for the next generation of memory devices; about a year later, the Advanced Research Projects Agency awarded the group \$5 million in a 50/50 split cost-sharing contract to develop DRAM devices using barium titanate thin films. ATMI has submitted patent applications covering the source gases, processes, and equipment used to produce barium titanate thin films.

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Puragen™ gas delivery systems improve the safety of semiconductor manufacturing while also improving chip quality.

■ **Safer and higher-quality chip production.**

ATMI has also developed products that improve the safety and the quality of chip production, through its line of gas and liquid delivery systems.

Semiconductor process gases—such as arsine, phosphine, and silane—have typically been available only in high-pressure cylinders, which can be dangerous if released. ATMI has developed new sources for these gases that improve safety and quality in semiconductor

production. Its safety-oriented patented product, called Puragen™, replaces high-pressure cylinders; hazardous gases such as arsine are adsorbed on a solid support and released on demand by adding heat or using a vacuum system. Because gas in this process is only produced as needed, less of the corrosive and toxic gas is present at one time. Gas pressure is also much lower (subatmospheric if desired) than for gas stored in pressurized cylinders.

This point-of-use gas delivery system, combined with in-line purifiers developed with U.S. Department of Energy SBIR funding and scrubbers developed with Environmental Protection Agency SBIR funding, led to the formation of a subsidiary, Novapure Corporation (Danbury, CT). Novapure was founded as a joint venture between Millipore and ATMI, with Millipore contributing equity and a

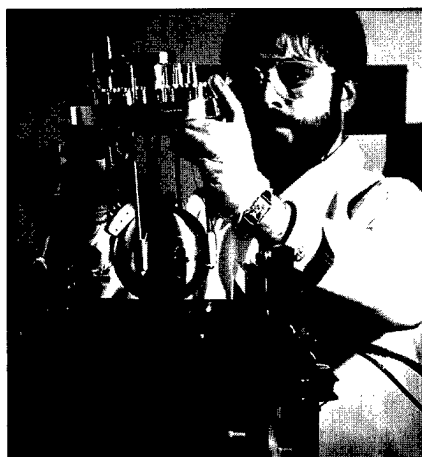
minority interest and ATMI contributing people, technology, and facilities.

In January 1994, Novapure entered into a strategic partnership with Matheson Gas Products, a subsidiary of Nippon Sanso, to jointly commercialize Novapure's Puragen™ Safety Delivery System. Selling for \$3,000 to \$5,000 depending on capacity and applications, Puragen™ is being marketed primarily to users of ion implantation and chemical beam epitaxy equipment.

In addition, ATMI's NovaMOS division is manufacturing and selling its LDS™ and Sparta™ liquid delivery systems, which the semiconductor industry can use to produce advanced dielectric and conductive thin films. These systems convert liquid precursors (and solid precursors in solution) into gases before they are injected into a CVD reactor. The systems allow multiple gases to be delivered with high precision. LDS™ and Sparta™ can be used to deposit both conventional materials, such as epitaxial silicon and silicon dioxide, and more exotic materials, such as barium strontium titanate and lead zirconate titanate (PZT).

■ **Other product areas.** ATMI is also developing an MOCVD process that uses mixed-metal precursors to make lead titanate and PZT—two materials that belong to a class of materials called ferroelectric oxides. These precursors inherently maintain the one-to-one ratio of lead to zirconate plus titanate, making it possible to concentrate on other important properties. For instance, ATMI can tailor PZT to meet the demands of specific applications, such as optimizing the dielectric constant for DRAM chips or the electro-optic effect for photonic switches, by varying the ratio of zirconate to titanate.

The properties of PZT thin films make it an attractive material for low-cost, nonvolatile random-access memory (RAM) devices, infrared and ultrasonic image sensors, and photonic switches. In addition, refinements in MOCVD processing could be extended to other oxides used to make insulator barriers and high-temperature superconductors.



■ **Researchers at ATMI analyze diamond cold cathodes, a promising material for next-generation flat-panel displays.**

Multichip Modules Stack High Against Alternatives

BMDO research in advanced packaging technology has led to a spinoff company, nChip, which is now selling between \$5 and \$10 million annually in multichip modules.

Spinning off into their own company called nChip (San Jose, CA), researchers previously at Lawrence Livermore National Laboratory, or LLNL, (Livermore, CA) are manufacturing and selling multichip modules (MCMs) developed with BMDO funding. Their success in commercialization has led to annual sales of \$5 to \$10 million.

MCMs are an advanced packaging technology that allow chips to operate 20- to 50-percent faster than conventional integrated circuit packaging while using about one-fourth of the space. By stacking the chip-to-chip interconnections in substrate layers, much less area is used and the wiring distance between chips is much shorter. MCM's smaller size and high performance give this technology an advantage over conventional packaging techniques. Applicable anywhere high-density electronic packaging is needed, this technology could benefit both commercial and defense users.

Since 1985, BMDO and the Advanced Research Projects Agency have funded the development of advanced packaging technology at LLNL for

space defense applications. When laboratory researchers spun off into nChip, they licensed six patents from LLNL and Stanford University so that they could manufacture and distribute MCM substrates and finished modules. nChip has sold MCMs to a wide variety

of customers, such as Ross Technology, Inc., (Austin, TX), which uses them in a notebook-sized SPARC workstation that Tadpole Technology (Austin, TX) introduced in early 1993. Other nChip customers include Silicon Graphics, Inc., (Mountain View, CA) and Control Data Systems, Inc. (Arden Hills, MN).

One of the hurdles in producing MCMs is their high price tag; costs must be significantly reduced before many of the mainstream electronics applications will be marketable. Therefore, nChip is participating in a \$40 million project awarded by the Technology

Reinvestment Project (TRP) to develop manufacturing and test tools. The 8-member team, led by GM Hughes Electronics, may make MCM a mainstream packaging technology in only 2 or 3 years, rather than a decade.

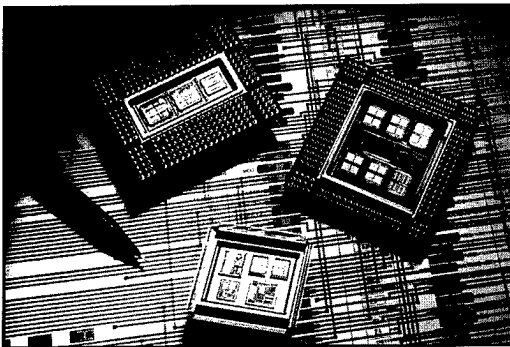
The MCM group is finding ways to increase production and lower manufacturing costs by working with production equipment suppliers to help them develop equipment tailored to MCM production. MCM producers are using a mixture of equipment originally designed to make and test semiconductors and printed wiring boards (PWBs). Building customized MCM production tools would reduce the mismatch between manufacturing needs and tool performance, resulting in lower production costs and higher device quality.

Other participants in the TRP multichip module consortium include Sandia National Laboratories (Albuquerque, NM), Polycon (Tempe, AZ), Texas Instruments (Dallas, TX), IBM (Hopewell Junction, NY), Micromodule Systems (Cupertino, CA), and Motorola (Chandler, AZ).

ABOUT THE TECHNOLOGY

Instead of adding more chips on a PWB, designers can package many chips together into a module that takes up less PWB space. The resulting package occupies, at most, one-fourth of the circuit board space normally used because the chips' footprint on the board and the interconnection circuitry are reduced.

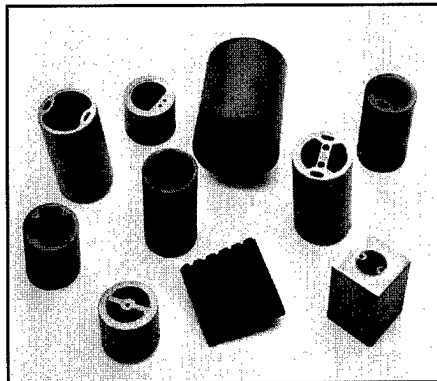
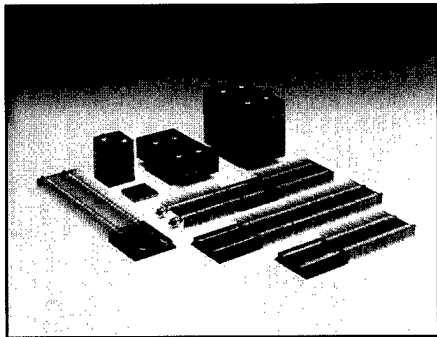
nChip uses silicon processing techniques including four patents on silicon circuit boards at LLNL and two patents on microchannel cooling from Stanford University. The company has been able to build MCMs by assembling up to 56 chips on a chiplike substrate that has its own high-density circuitry. Its specialty is silicon substrates with silicon dioxide substrate dielectric and either aluminum or copper metallization. This mix provides the best balance for high-performance, thermal dissipation, ease of manufacture, reliability, and cost.



■ The multichip module is an advanced packaging technology that allows chips to operate 20- to 50-percent faster than conventional integrated circuit packaging while using about one-fourth of the space.

Wicks Work Against Gravity To Cool Chips

With two BMDO-related patents for its metal wicks, Thermacore, Inc., sells more than 30,000 heat pipes and assemblies a year to cool electronic devices.



■ Thermacore's heat pipes (top) with porous metal wicks (bottom) can be used almost anywhere uniform temperature is important. The largest market is cooling microelectronic and electronic devices, such as computer chips and laser diodes.

Cooling is becoming an increasingly important consideration for semiconductor manufacturers, who are now producing smaller, high-circuit-density, high-performance chips. Such compact packages produce lots of unwanted heat, which lowers performance and is difficult to dissipate by conventional passive techniques.

Thermacore, Inc., (Lancaster, PA) is marketing heat pipes with porous metal wicks that are ideal for cooling microelectronic and electronic devices, such as computer chips and laser diodes. These compact, super-efficient, and highly reliable cooling devices can be used

almost anywhere uniform temperature is important. For example, they can be used for printed circuit cards, which need cooling plates to prevent them from expanding unevenly.

Holding two patents for its BMDO-funded research on metal wicks, Thermacore sells more than 30,000 heat pipes and assemblies a year to cool electronic devices. In fact, the company has built a new factory facility for mass production.

Heat pipes can also be used in energy applications such as solar receivers, which require a device to transfer heat of high temperatures with minimal heat loss. Thermacore's heat pipes were part of an R&D 100 award-winning solar dynamic power system. This system used heat pipes to transfer heat from the solar

receiver to a Stirling engine. Sandia National Laboratories, Cummins Power Generation, Inc., and Sunpower, Inc., were also recipients of the award.

Through the BMDO SBIR program, Thermacore has developed heat pipes for a wide range of uses, such as cooling laser mirrors, electron tubes, and batteries through variable conductance. The company's devices can also be used for heat pumps.

ABOUT THE TECHNOLOGY

Heat pipes are compact, reliable, and super-efficient devices for heat transfer that could improve many thermal management processes. Heat is added to one end of the pipe, and a liquid inside evaporates into a vapor, absorbing heat. The vapor then flows to the other end of the pipe. Because this end is colder than the other, the vapor condenses back into a liquid, thereby releasing heat.

To repeat the cycle, a wick absorbs the condensed liquid and transports it back to the hot end. The wick moves the liquid by capillary forces, the same forces that allow a wick in a kerosene lantern to pull kerosene from the canister to the point of combustion.

Unfortunately, most heat pipe wicks are not as efficient as lantern wicks; they do not provide enough capillary force to move liquid against the force of gravity. As a result, most heat pipes only work if the cold end is above the hot end.

These technology limitations reduced the list of candidate users of heat pipes to only a handful of often-high-ticket applications. Applications have been limited because the device being cooled must be situated for gravity to work with, and not against, the heat pipe.

Thermacore's porous metal wicks, however, have enough capillary pull to transport liquid against the force of gravity. With stronger capillary pull, Thermacore's porous metal wicks increase the thermal efficiency of the heat pipe, allowing heat pipes to be used in traditional applications.

Probe Analyzes Semiconductor Components

A new product called BEESBox™, a research consortium, and a 1990 R&D 100 award from R&D Magazine have all resulted from BMDO-funded research on ballistic electron emission microscopy.

Researchers at the Jet Propulsion Laboratory, or JPL, (Pasadena, CA) and Surface/Interface Inc. (Mountain View, CA) are pursuing semiconducting markets with their award-winning technology called BEEM. Short for ballistic electron emission microscopy, BEEM was developed by JPL to study atomic structures by probing several hundred angstroms beneath the surface of a material.

The BMDO IS&T program funded generic research at JPL that led to BEEM, which is primarily used to study semiconductor devices. BEEM has become a major research tool to analyze semiconductor interfaces since its invention in 1988. In fact, an international conference is now held annually on the subject.

JPL has licensed this patented technology to Surface/Interface, which now markets a BEEM system known as BEESBox™. Selling for about \$60,000, the BEESBox™ system includes BEEM hardware, support electronics, data handling capabilities, and reduction software. The primary customers for BEEM systems are research laboratories, although higher-volume applications are appearing in semiconductor design and manufacturing. JPL has also had

discussions with several other companies interested in commercializing BEEM technology.

Research on BEEM has also resulted in a consortium between the University of California at Santa Barbara, California's Microelectronics and Computer Research Opportunities (MICRO)

program, JPL, and Surface/Interface. This team is increasing the potential of BEEM by finding ways to make it usable at temperatures as low as 0.3 kelvin. BEEM could study several important effects in the operation of semiconductor devices that occur only at low temperatures or produce an almost undetectable signal at room temperature.

The consortium is also planning to make a silicon semiconductor tip, used to produce tunneling electrons used by BEEM. This tip will

provide better resolution than currently used tips (usually made of gold or platinum).

Surface/Interface has contributed cash, equipment, software, and the initial research prototype to this project. In return, both the low-temperature BEEM design and the tip technology will be transferred to the company.

ABOUT THE TECHNOLOGY

Most of the physically interesting activity in semiconductors occurs in buried interfaces, the part of a semiconductor where one material meets the other. Because BEEM can probe hundreds of angstroms beneath a semiconductor interface without destroying the device's internal structure, it can provide previously unattainable information about the buried interface.

To operate, BEEM exploits an anomaly of scanning-tunneling microscopy (STM)—the existence of "ballistic" electrons. (STM has been used widely to map the atomic bumps and valleys of material surfaces, producing a breakthrough in researchers' ability to see atomic structure, as discussed on page 40 of this report.)

The STM uses the quantum-mechanical effect of electron tunneling to measure the separation between a fine-pointed stylus and a surface under analysis. When a small voltage difference is applied between these two electrodes, electrons can tunnel from the tip to the surface, thereby producing a tunneling current. This tunneling current gets stronger as the tip moves closer to the surface. As a result, this current can measure variations in the surface of the material under analysis.

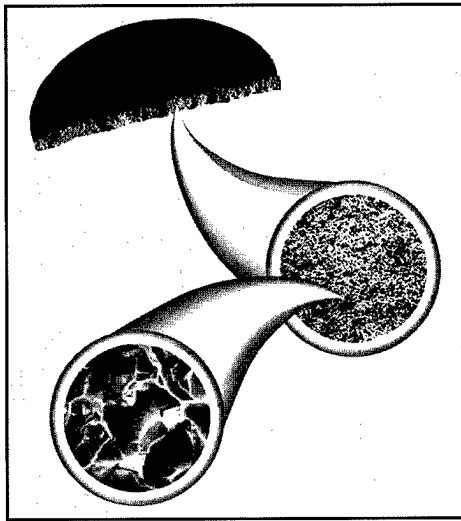
In BEEM, JPL has added a third electrode to a standard STM to collect ballistic electrons—those that penetrate a surface as much as several hundred angstroms without scattering or losing energy. The resulting current provides the first direct images and information about the subsurface material quality and interface structure.



■ A Surface/Interface employee placing a sample in the company's BEESBox™, a commercially available BEEM system manufactured through a license from JPL.

Dymalloy Cools Chips Better At Lower Cost

Government and industry have teamed together to develop Dymalloy, a cheaper and better way to cool microelectronics.



■ The figure shows two magnified views of the fracture surface of a Dymalloy disk. The lower-magnification image shows the uniform distribution of diamond in the metal matrix. The higher-magnification image at the bottom of the figure reveals high-strength cleavage failure in the diamond particles.

As electronic circuit designs become more compact, engineers are more challenged by the heat that the tiny electronic components generate. Such accumulated heat raises the device's temperature, stressing semiconductor chip-to-substrate connections and reducing the chip's operating life.

To solve problems with thermal stress, Lawrence Livermore National Laboratory, or LLNL, (Livermore, CA) and Sun Microsystems, Inc., (Mountain View, CA) have teamed together to find cheaper and better ways for cooling microelectronics. They have developed a dia-

mond powder composite material called Dymalloy, which costs 25 times less than diamond for the same-sized application and conducts heat twice as well as commonly used alloys.

The team participated in a 1-year, \$350,000 cooperative research and development agreement (CRADA) to capitalize on diamond's unmatched thermal conductivity. While LLNL enhanced the material, Sun Microsystems tested multichip modules with substrates made from Dymalloy

to verify that the material conducts heat away from the densely packed circuitry better than currently used materials.

Workstations, and eventually personal computers, could benefit from this material. Workstations now use high-density, powerful microprocessors that generate lots of heat. They could be mounted on a base of Dymalloy to increase operating life. Component designers could also use the composite material to create robust modules that tolerate higher operating temperatures. Sun Microsystems is commercializing Dymalloy and expects that multichip modules with such substrates could be used in workstations in about 2 years. The company is looking for a material manufacturer.

In a 2-year effort at LLNL, BMDO funded work on Dymalloy for Brilliant Pebbles to improve substrates of electrical components. The material could dissipate the heat generated by high-density electronic components used in ballistic missile detection and interception. LLNL is pursuing a patent on the alloy process.

ABOUT THE TECHNOLOGY

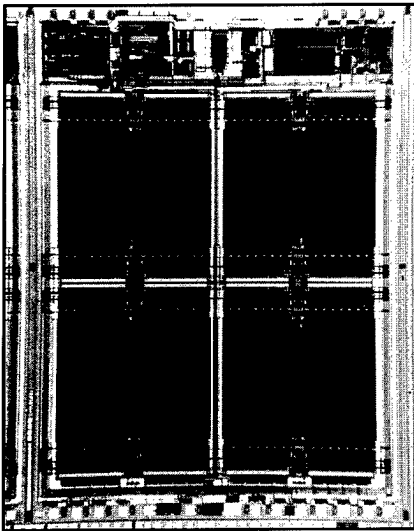
Scientists created Dymalloy to take advantage of diamond's thermal conductivity while avoiding its high cost. Even the cost of diamond thin films, made by chemical vapor deposition, is too high for most applications. Diamond films cost up to \$5,000 for a coating on a 4-inch-square wafer but have a superior thermal conductivity of 14 watts per centimeter-kelvin (W/cm-K). A Dymalloy substrate of the same size would cost \$200, and at 4 W/cm-K, would have about twice the thermal conductivity of copper-tungsten alloy, a commonly used substrate material.

To make Dymalloy, LLNL scientists use a commercially available low-grade diamond powder produced synthetically or as a byproduct of industrial diamond processing. The diamond powder is embedded in a matrix of copper and silver, creating a malleable alloy suitable for electronics processing. LLNL's alloy process brings together diamond and copper in one material, despite the materials' resistance to such bonding. LLNL is testing various grades of diamond powder to determine the best grade for heat conduction and substrate manufacturing.

Unlike today's substrate materials, Dymalloy expands and contracts at about the same rate as silicon during temperature changes. A similar coefficient of thermal expansion reduces stress on the chip-to-substrate junction. Silicon has a coefficient of thermal expansion of 4.2 parts per million per degree Celsius (ppm/°C), compatible with Dymalloy at 5.8 ppm/°C, while copper tungsten has a coefficient of thermal expansion of 8.3 ppm/°C. Dymalloy could also replace copper tungsten as a substrate.

New Materials For MRAM To Capture Memory Market

In collaboration with a domestic memory producer, Nonvolatile Electronics, Inc., is approaching the static and dynamic memory markets with its BMDO SBIR-funded technology.



■ The developmental MRAM is roughly 0.5 by 8.3 centimeters, with feature sizes of 0.7 microns. The technology is aiming for 0.05 micron features, enabling 500-megabyte memories in 2 centimeters.

Nonvolatile Electronics, Inc., or NVE, (Plymouth, MN) is approaching static and dynamic memory markets with developments in magnetoresistive random access memory (MRAM). With radiation hardness, compact design, and fast access times, this memory technology combines the best features of both main and disk memory storage all in one package.

NVE has developed giant magnetoresistive ratio (GMR) materials that increase magnetoresistance to 3 to 20 times that of previous MRAM materials. GMR materials—alternating thin films of ferromagnetic material and nonferromagnetic conductors—yield lower read access times, which are needed to build high-density memory chips for circuitry.

Pursuing partnerships with large semiconductor producers, NVE has had one development program with a domestic memory producer since December 1992. Using GMR, NVE is planning to market its 16-kilobit MRAM commercially, along with niche products like an octal latch and a programmable resistor.

In the short term, 16-kilobit MRAM could replace magnetic core and bubble memory, reducing cost and power requirements, while improving performance over current technology. This memory could be used in applications where many write and read cycles occur over a wide temperature range.

MRAM could also replace the various versions of static and dynamic computer memory, such as magnetic disks, battery-backed static RAM (SRAM), electrically erasable programmable read-only memory (EEPROM), and flash memory. MRAM offers a competitive advantage over other memory cells, providing fast, unlimited writes using low energy and indefinite data retention. In addition, MRAM could compete against the workhorse of computer memory, dynamic RAM (DRAM) if, as predicted, design constraints limit the future capability of DRAM cells.

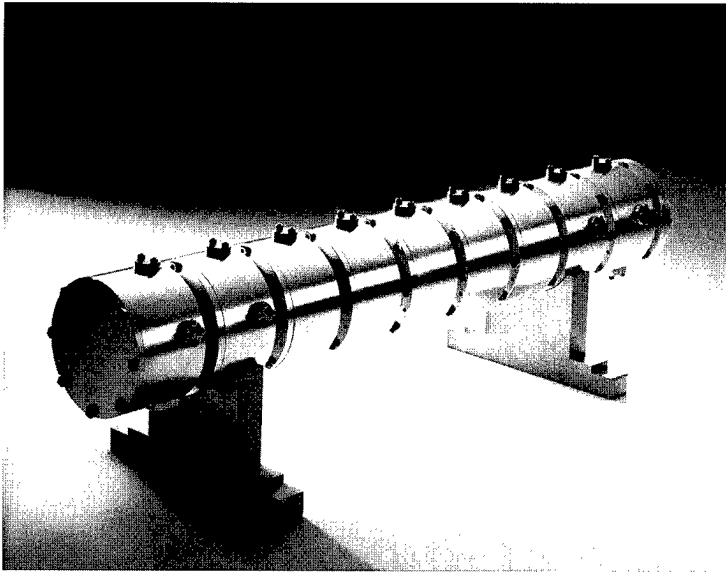
NVE is also researching GMR materials to improve hard disk drive read heads or data sensors—a use that could increase the density of data storage. GMR materials could also be used in position, current, magnetic field, and velocity sensors.

ABOUT THE TECHNOLOGY

Magnetic storage offers the benefits of memory durability and radiation hardness, while silicon memory chips provide small packaging and fast access times; neither technology has all four advantages. On the other hand, since MRAM does offer all these benefits, it could potentially replace the two most common types of computer memory—main and disk memory.

To effectively compete with commonly used computer memory, developers of MRAM will have to remedy problems with the low signal levels found at high cell densities. These signals currently require either long access times to read the contents of the memory cell or more chip surface area per cell to improve performance. NVE's GMR materials solve this problem by improving read access times. BMDO has acknowledged MRAM's benefits for weapons and space systems and has funded SBIR contracts at NVE to develop GMR materials and to design higher-density MRAM cells.

The founder of NVE, Dr. James Daughton, invented MRAMs in 1984 while at Honeywell, Inc. Both NVE and Honeywell have designed and demonstrated a 16-kilobit MRAM. NVE is developing a 1-megabit MRAM and is demonstrating memory cells made with 0.8-micron-scale lithography to prove the competitiveness of MRAM. The state of the art for low-volume dynamic random access memory production is 0.5 micron. NVE plans to demonstrate 0.2-micron, and smaller, memory cells.



*Illinois Superconductor
Corporation,
page 80*

Superconductors

Since the discovery of high-temperature superconducting (HTS) materials in the mid-1980s, superconductor R&D has exploded, with visionary forecasts of revolutionary uses of superconductivity in virtually every process where electricity is used. The discovery introduced materials that can conduct current with virtually no resistance at the boiling temperature of liquid nitrogen (77 kelvins, or -196 degrees Celsius)—well above the much more difficult to obtain liquid-helium temperatures (4 kelvins, or -269 degrees Celsius) required for more conventional superconducting materials. While these frosty requirements may be deemed a bit chilly by some standards, the new materials proved to be a hot enough breakthrough to release superconductivity from the laboratory basement onto the production line.

Scientists have been examining ways that both high- and low-temperature superconductors could enable applications in areas such as magnetically levitated trains, computers with ultrafast capabilities, and more efficient systems for utilities. Superconducting materials can also be used—and are being used—in magnetic resonance imaging and high-performance communications.

After 7 more years of R&D, the general public is still not riding on magnetically levitated trains; however, superconductivity has made great strides toward commercialization, with a present global market estimated to be \$1.5 billion. The real significance in this area is that new products from this research are reaching the market, and companies specializing in superconductors have recently gone public.

BMDO has been at the forefront in superconductivity in terms of both R&D and commercial products. For example, BMDO partially funded development of a new compound that superconducts at the highest temperature ever recorded for superconductivity (164 kelvins, or -109 degrees Celsius) at the University of Houston's Texas Center for Superconductivity. (This record was set in 1993; continuous advances building on this research may have increased this temperature by the time you read this report.) In addition, three BMDO-funded companies have recently gone public, and all of them have products on the market. They are Superconductor Technologies, Inc., (Santa Barbara, CA), Illinois Superconductor, Inc., (Evanston, IL), and Conductus (Sunnyvale, CA). The following section describes a few examples of commercialization activities of BMDO-funded companies.

¹ Marketing information compiled at the second International Superconductivity Industry Summit in May 1993 (Hakone, Japan).

Superconductors Make Car Phone Calls Clear, Improve Power Quality

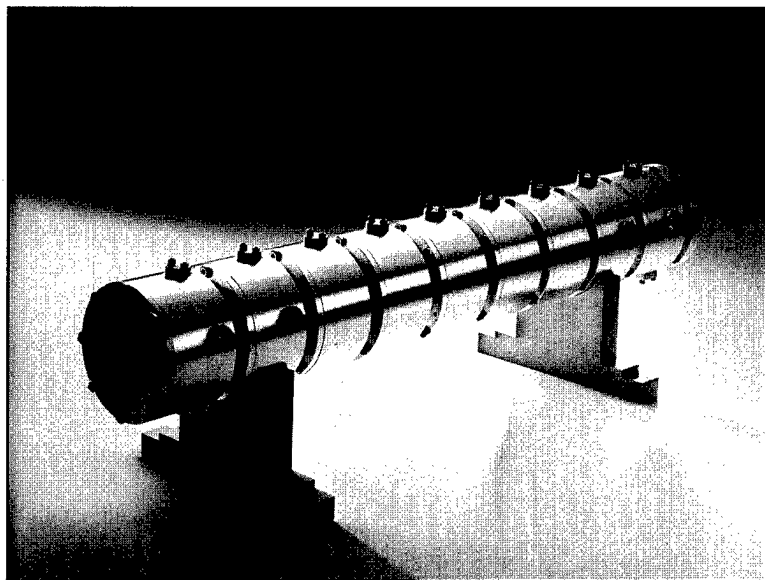
With new products on the horizon, research in thick-film technology is being applied to a \$3.5 million Advanced Technology Program project to improve the performance of cellular communications.

From cellular communications components to power leads, devices developed by Illinois Superconductor Corporation, or ISC, (Evanston, IL) are using high-temperature superconducting (HTS) technology partially funded by BMDO. ISC's innovative research and resulting products—with more on the way—led to the company's successful initial public offering in 1993. ISC is commercializing BMDO-funded technology in two areas.

In one area, ISC has found a way to reduce annoying distortion and dropped phone calls in cellular communications. Collaborating with ICI Superconductors (Birmingham, England), ISC is further developing thick-film HTS components—work partially funded several years ago by BMDO at ICI for space-based applications. The two companies' findings have led to ISC's participation in a 3-year, \$3.5 million Advanced Technology Program (ATP) project to develop and demonstrate HTS components for cellular base stations. ISC plans to have a

ways. For example, HTS multi-bandpass filters will be competitive in cost with high-end ceramic filters. And since superconducting technology reduces the interference from transmitters in other radio services, base stations can be more flexible when selecting cell sites. In addition, receivers are more sensitive, which improves the performance of hand-held cellular phones and other low-power wireless systems, and guard band allocations are reduced, allowing carriers to maximize the use of their frequencies.

HTS thick-film technology can also be applied to other electronics and communications applications, such as receivers for two-way radios, radar, and satellites. The group working with thick-film technology at ICI Superconductors is currently manufacturing and selling circuits, antennas, resonators, shields, current leads, and flux transformers. Some of the research that was conducted for BMDO is being applied to its product line, especially in the area of shields. The company has recently relocated from Cleveland, England, to the University of Birmingham, where it is working closely with the University.



■ The photograph above illustrates a cellular filter installed in a liquid-nitrogen dewar.

prototype ready by late 1994, and at the same time, the company, which recently went public, will begin selling its base station receivers, including filters. Other participants in the ATP project include AT&T Bell Laboratories and one or more cellular operating companies.

ISC's and ICI's thick-film technology can improve cellular communications in several

ABOUT THICK-FILM TECHNOLOGY

Thick film's advantage over thin-film technology is that it enables 3-dimensional objects to be coated. This capability not only allows superconducting devices to be formed into unconventional shapes to "fit" into systems, but it also allows developers to design device shapes that will be unaffected by problematic magnetic fields, which can disrupt the performance of HTS components. Thick-film material is also easier, faster, and cheaper to apply onto components. It can be sprayed, dip-coated, or brushed onto desired substrates, rather than requiring a sophisticated laser process.

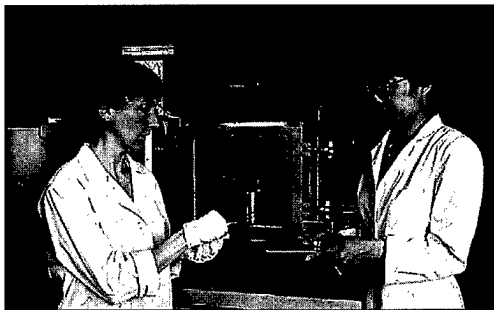
continued on page 81

A BMDO SBIR contract is helping Illinois Superconductor Corporation develop a superconducting switch, that could be used to control utility power loads; this research has already contributed to the company's power lead product line.

continued from page 80

On another project, ISC is using BMDO SBIR funding to control electrical current surges with HTS thick films and filaments. The company's superconducting switch, or fault current limiter, is nearly a thousand times faster than a conventional surge protector and can shut off an electrical surge in less than a millionth of a second.

Electric utilities have the most to gain from ISC's technology. Because of their complexity, utility grids must contend with rapid fluctuations in the power load and power surges often caused by lightning strikes and equipment short circuits. The utilities generally protect their grids from these power surges using two methods: (1) overdesigning the equipment and instruments attached to the power system—a somewhat costly and cumbersome approach—or (2) using inductors, which produce waste heat, dissipate electricity, and require ventilation. ISC's HTS fault current limiter would be faster than conventional methods for surge protection and should generate and dissipate significantly less heat than inductors.



■ ISC researchers used bare filaments of YBCO but are also experimenting with thick-film superconducting technology (as shown above) by applying YBCO onto MgO or stainless steel.

This technology could also benefit manufacturers, such as those in the semiconductor industry, that rely heavily on power quality. These manufacturers could install the HTS fault current limiters on site to prevent costly downtime.

ISC's research in this area has resulted in the manufacture and commercial sale of low-temperature superconducting current lead parts, which are now selling for use in low-temperature magnet components.

ISC evolved from Argonne National Laboratory (ANL) in 1990 to commercialize the laboratory's technologies with investment funds from ARCH Development Corporation; Batterson, Johnson, and Wang Venture Partners; and the State of Illinois. In addition to ANL's technology, ISC has incorporated the results of research at Northwestern University. The concept for the fault current limiter originated from ANL,

with which ISC has a nonexclusive license. ISC received an SBIR contract to further develop this technology for space power and other BMDO applications.

ABOUT THE FAULT CURRENT LIMITER

An important aspect of a superconducting component is its current-carrying capacity. When an electrical current is applied that matches the capacity of the component, cryocooled superconducting materials conduct the electricity without loss. But if the superconducting component receives a power surge beyond its capacity, it loses most of its superconducting qualities and acts as a resistor.

In ISC's technology, an HTS fault current limiter is operated in parallel with a conventional resistor. In normal operation, most of the current flows through the low-resistance HTS switch, while the resistor carries only a small fraction of the current. When a power surge exceeds the current capacity of the HTS switch, the switch becomes resistive rather than superconducting. Because the HTS switch has shut down, the only current path remaining is through the resistor, which suppresses the surge. The HTS fault current limiter quickly returns to its superconducting state and resumes current load once the surge conditions have abated.

For the BMDO project, ISC used bare filaments of yttrium barium copper oxide (YBCO), an HTS material. The company is also experimenting with thick-film superconducting technology by applying YBCO onto magnesium oxide (MgO) or stainless steel.

Hybrid Chips Lead To Smaller, Speedier Devices

Partially funded by the BMDO SBIR program, this cooperative research and development agreement for hybrid chips is contributing to the Conductus product line.

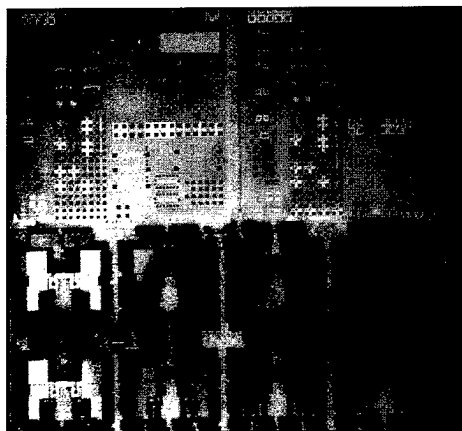
From oil exploration to fiber-optic communications, Conductus (Sunnyvale, CA) is finding new uses for hybrid high-temperature superconducting (HTS)/semiconducting circuits. These circuits, partially funded by the BMDO SBIR program, were developed in conjunction with the Naval Command, Control, and Ocean Surveillance Center (NCCOSC) through a cooperative research and development agreement (CRADA).

The CRADA team has incorporated a complementary metal oxide semiconductor (CMOS) transistor with a Josephson junction, the superconducting equivalent of the transistor. Placing the complementary CMOS/HTS components on the same chip at 77 kelvins can lead to chip performance, such as high-density memories and very fast speeds, that neither component can attain alone.

The CRADA developments are contributing to Conductus' new product line of superconducting quantum interference devices, or SQUIDs,

expected to be on the market soon. With major applications in magnetic sensing, SQUIDs can detect signals 10,000 times smaller than those detected by other magnetometers.

Among other applications, SQUIDs can be used for geophysical surveying equipment to locate oil and mineral deposits in a technique called cross-hole electromagnetic borehole logging. This technique is important because it may help explorers locate substantial portions of the earth's remaining oil deposits that cannot be found using standard seismic techniques. In this technique, a magnetic sensor is lowered down a narrow borehole to map electrical resistivity of the adjacent earth, and the sensor receives signals from a remote transmitter. To obtain the needed magnetic sensitivity, conventional copper sensor coils need to be at least 10 feet long, but SQUIDs are much smaller and offer portability and performance advantages over copper coils.



■ Shown above are Conductus' HTS materials monolithically integrated with silicon-on-sapphire CMOS. The hybrid chip allows for microelectronic advances such as fast speeds of up to 100 gigahertz, along with the ability to form latches.

The CRADA would reduce the size of SQUID support electronics, making SQUID-based systems even smaller for these magnetic sensing applications. SQUIDs now require room-temperature support electronics that are roughly the size of two coffee cups; the SQUID chip itself is at cryogenic temperatures. A complete SQUID using hybrid chips would be much smaller and would require only three or four small interconnect wires, lowering the thermal load on the cryogenic system.

The hybrid HTS/CMOS chip could also be used for gigabit fiber-optic communications or advanced signal processors for applications such as 3-dimensional imaging of biological and industrial specimens. Such hybrid chips would enable computers to operate at lower power and faster speeds (up to 100 gigahertz). The chips would also allow for high-density memories, level-shifting interface circuits, and latches for readouts.

ABOUT THE TECHNOLOGY

NCCOSC has combined its expertise in developing silicon-on-sapphire CMOS technology with Conductus' experience in developing HTS thin films. The team's hybrid chips combine the advantages of both HTS and CMOS devices. These advantages include fast speeds of up to 100 GHz, ability to form latches and level-shifting interface circuits, and increased speeds of CMOS technology by a factor of 2—a result of cryogenic cooling.

Previous attempts to incorporate HTS materials on semiconductors were unsuccessful because HTS materials are generally incompatible with silicon and gallium arsenide for practical purposes. The team used a sapphire substrate for the chip because this material is compatible with both the CMOS and YBCO. Sapphire allows YBCO and silicon to grow epitaxially but prevents yttrium, barium, and copper from diffusing. In addition, silicon nitride was used as a diffusion barrier to protect the CMOS from copper contamination during HTS fabrication.

Superconducting Device Stops Electrical Current

IAP Research has developed a high-temperature superconducting device that can be used to protect expensive equipment and processes, such as those in semiconductor production.

IAP Research (Dayton, OH) has developed a high-temperature superconducting (HTS) device that is designed to actually *stop* current. Called a fault current limiter, this device uses HTS thin-film technology to protect electrical equipment from damaging and costly power surges. IAP Research's device performs much better than high-speed fuses, which stop 3 to 4 orders of magnitude less fault current.

This small solid-state device (20 square millimeters) serves as a circuit breaker, using a "fold-back" design. In this design, when current capacity is exceeded, the HTS component no longer superconducts. Instead, it acts as a resistor and shuts off the current. After the excessive voltage is removed, the fault current limiter acts like a resettable fuse and quickly becomes superconducting again.

IAP Research's technology can be used to protect expensive equipment and manufacturing processes from power surges, such as critical manufacturing processing in the semiconductor industry, high-voltage radio-frequency

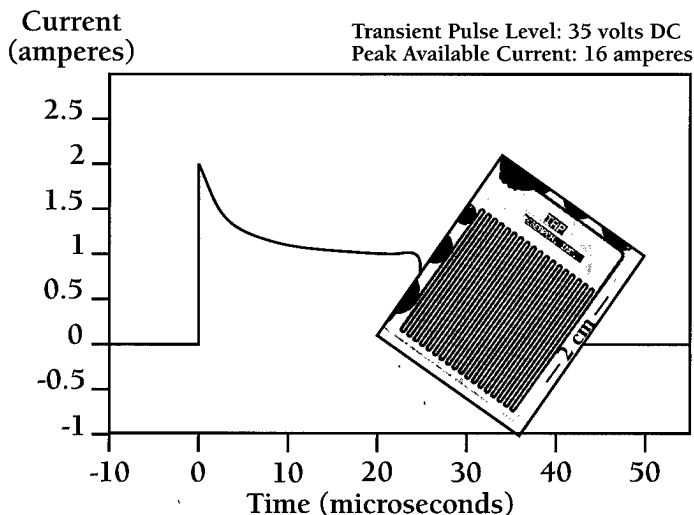
Further into the future, some of the applications for the fault current limiter are for both power system protection and load protection. Utilities could use such devices to protect generators and distribution lines from fault current. They could also use the device to stabilize power systems in large urban areas where multiple transmission lines, connected in parallel, can cross-talk and potentially cause power outages. This type of cross talking was the primary cause of the major blackout in New York City in the early 1970s. IAP Research has conducted an independent market study to identify niche markets and is currently looking for interested parties to join in a demonstration of its current limiter.

ABOUT THE TECHNOLOGY

The current carrying capacity affects the performance—and, in this case, the use—of a superconducting component. When an electrical current is applied that matches capacity, cryocooled superconducting materials conduct the electricity at near-zero resistance. But if the superconducting component receives a power surge beyond its capacity, it stops working. It quickly loses its superconductive qualities and acts as a resistor.

In tests, IAP Research used a design with a critical current of 2 ampere and a blocking capability of 35 volts. The device turned off current in less than a microsecond and turned it back on in tens of microseconds. When operating below the critical current, the fault current limiter also demonstrated less than a 0.5-volt drop when inserted into the system (primarily due to leads). This technology can also be designed for other currents for limiting current and blocking voltage and can be used for AC and DC power circuits. Blocking capabilities are expected to be up to 1,000 volts.

IAP Research has demonstrated the basic technology to design and make fault current limiters with metal current contacts and terminations. The company has also defined limiting current, blocking voltage, and current fold-back characteristics.

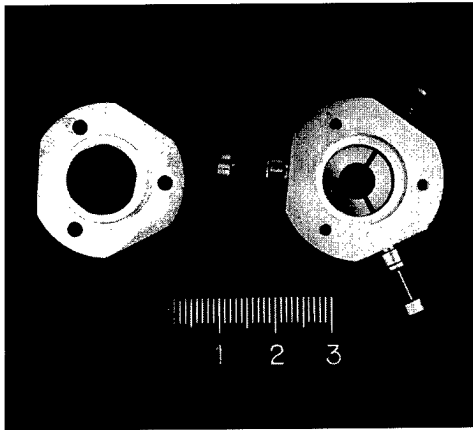


■ In tests, IAP Research's HTS fault current limiter turned off current in less than a microsecond and turned it back on in tens of microseconds.

vacuum tubes (which cost up to \$1 million), and supercomputers. In fact, this application was exactly the reason why the BMDO SBIR program funded IAP Research's work—to demonstrate a current limiting device that protects defense-related power loads from current damage during circuit faults.

Superconducting R&D Translates To Product Sales

Neocera is selling a byproduct of BMDO SBIR funding—a pulsed laser deposition device that can be used for applications such as semiconductor production and medical implants.



■ By applying HTS technology to non-reciprocal components (as shown above) and integrating them into a system, developers can produce a complete HTS integrated microwave circuit.

As a byproduct of the company's BMDO-funded research, Neocera (College Park, MD) is now selling a pulsed laser deposition device called the Automated Target Carousel Flange Assembly. This device can be used in areas such as semiconductor manufacturing and medical implants to deposit a variety of complex materials, including oxides, nitrides, sulfides, carbides, and alloys. Neocera has attracted considerable interest from the research community and has already sold a few devices, which retail for about \$18,000 each.

Through this BMDO-funded SBIR contract, Neocera and the David Sarnoff Research Center (Princeton, NJ) are developing high-temperature superconducting (HTS) microwave communications components, such as circulators and isolators. Significantly improving performance over current technology, these devices would enable miniature integrated microwave

circuits to be made with reduced interconnect losses. Neocera is applying its expertise in pulsed laser deposition and metal-oxide materials to develop superconducting nonreciprocal devices. David Sarnoff Research Center is providing expertise in microwave circuit fabrication and testing.

Neocera is also marketing thin films. Much of its product line has been developed

through research on SBIR contracts funded by BMDO and other agencies. High-quality HTS superconductors deposited onto ferrimagnetic and related substrates within the garnet family can be applied to a variety of technologies, including radar, radio-frequency and cellular communications, microelectronics, and sensors.

The company is affiliated with the Technology Advancement Program at the University of Maryland, which supports start-up companies to foster its high-technology industrial base. In 1993, product sales at Neocera accounted for over 12 percent of the company's total revenue, as compared with under 4 percent in 1992. This percentage is expected to approach 30 percent in 1994.

ABOUT THE TECHNOLOGY

While researchers have applied HTS microwave technology to components of various systems, far fewer integrated systems have been designed. Such integrated designs are essential for HTS technology to be successfully implemented for practical applications.

A variety of HTS microwave components, such as filters and delay lines, have been demonstrated that perform better, weigh less, and occupy less space than state-of-the-art nonsuperconducting components; however, practical microwave systems also require compatible components that are known by those in the industry as nonreciprocal devices. These devices reduce performance-limiting interactions between the individual components. By applying HTS technology to these nonreciprocal components, such as circulators and isolators, and integrating them into a system, developers can produce a complete HTS integrated microwave circuit.

To make these devices, researchers at the company have found a way to deposit HTS thin films of yttrium barium copper oxide (YBCO) onto ferrimagnetic substrates such as yttrium iron garnet. (Ferrimagnetic materials can be magnetized by applying a sufficiently strong magnetic field. They differ from ferromagnets such as iron on a microscopic level.)

Through lattice engineering, Neocera has successfully developed a proprietary multilayer technology using one or more buffer layers that permit microwave-quality YBCO to be grown on ferrimagnetic substrates. To facilitate the growth of the multilayer thin-film structures, Neocera has enhanced its pulsed laser deposition equipment through the development of the Automated Target Carousel Flange Assembly.

TRW Finds A Faster Fabrication Process

Using innovative fabrication techniques, TRW has participated in several joint efforts to develop superconducting digital circuits.

Superconducting integrated circuits (ICs) could be ideal for electronic processes. They are much faster than conventional ICs while requiring orders of magnitude less power—only a few milliwatts per circuit—than high-speed semiconductor circuits.

Such speedy circuits could significantly improve electronic processes for aircraft and satellites, neural networks, radar, and communications. But these smaller and faster components have faced commercialization barriers, in part, because they are difficult to manufacture.

Researchers at TRW (Redondo Beach, CA) are finding faster and easier ways to mass-produce superconducting integrated circuits. Partially funded through BMDO, they have found a way to use standard semiconductor manufacturing processes to make superconducting Josephson digital circuits. These processes have fewer and

simpler production steps, allowing the circuits to be mass-produced. TRW has made its low-temperature superconducting (LTS) niobium nitride and niobium foundries available to other companies for making superconducting materials used in the design, fabrication, and testing of LTS components.

In addition, TRW has entered into several joint efforts with other aerospace and commercial

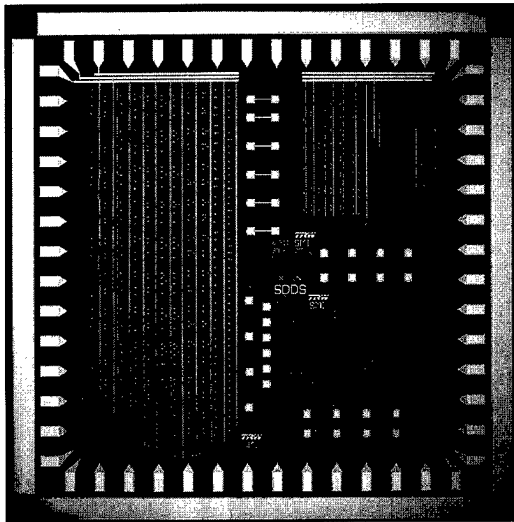
companies to develop superconducting digital circuits. For example, through the Advanced Technology Program, TRW is participating in a consortium to develop an IC that will be used to build ultrafast (5- to 10-gigahertz) digital signal processors. Other players are Conductus, Stanford University, and the University of California at Berkeley. In another project, TRW is working with another partner to develop superconducting digital signal processors with multigigahertz bandwidths, hertz resolution, and spurious noise below -47 decibels.

BMDO's IS&T and Materials and Structures (M&S) programs funded these technologies primarily to develop fast and accurate surveillance system detectors and on-focal-plane digital signal processing. BMDO's M&S program has also supported foundry development and circuit yield improvements for LTS ICs to enable low-cost, compact digital processors on satellite systems.

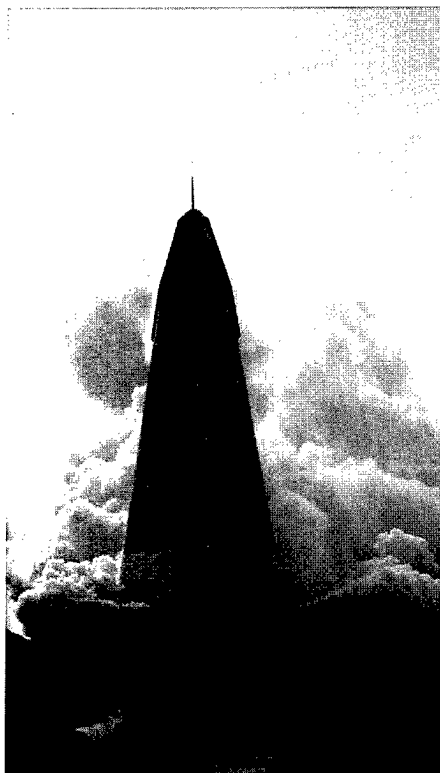
ABOUT THE TECHNOLOGY

Superconducting Josephson digital ICs are intrinsically the fastest (picosecond gate propagation delay) of known electronic technology, yet require orders of magnitude less power (microwatts to nanowatts per gate) than high-speed semiconductor circuits. TRW has developed three technologies for the fabrication of the superconducting Josephson digital ICs. Two—niobium and niobium nitride (NbN)—are refractory metal (LTS) thin-film circuit technologies. The third is a copper oxide high-temperature superconductor.

To keep fabrication costs down for the LTS ICs, TRW uses thin-film processes on silicon substrates with only 8 to 12 mask steps. TRW's NbN IC combines high-speed/low-power Josephson circuits with 0- to 10-kelvin operation and circuit complexity greater than 300 gates per chip. In addition, present superconductor IC fabrication capabilities may allow TRW to produce thousands of gates per chip within a year. The high temperature superconducting technology is also fabricated through thin-film processing.



■ TRW's novel fabrication process may allow the company to produce thousands of gates per chip within a year.



*McDonnell Douglas
Aerospace,
page 90*

Dual-Use Technologies

You probably have recently read articles about dual-use technologies—technologies that can serve the interests of the commercial sector as well as the defense community. Many agencies are finding that funding R&D in areas shared by both government and industry can offer many technological and economic advantages to businesses and taxpayers alike, capitalizing on systems that are already being built. In addition, agencies have begun working together in teams on dual-use projects that serve different government-related needs, in light of recent budget cuts that many agencies (and laboratories) are facing.

Almost every technology in this report could be considered dual use—serving defense, industry, and other government agencies. Many of these technologies are components designed for larger BMDO systems. The following section, however, is different because it describes examples of large-scale dual-use projects that can benefit, or already have benefitted industry and other agencies when used as a whole.

One such system, called the Clementine space probe, has already completed its mission, providing new lunar data for the National Aeronautics and Space Administration while testing new BMDO-funded technology, which can also be used for commercial satellite businesses. Another system, called the Delta Clipper Experiment, is a reusable single-stage-to-orbit rocket. Still in the prototype phase, this flight vehicle could offer numerous economic benefits to the aerospace industry. This section also discusses a satellite-based system called LaserCom that transmits information with lasers instead of radio-frequency waves, thereby increasing the speed and quality of communications between satellites.

On a more abstract level, this section addresses an aspect of dual-use R&D, coined "intellectual technology transfer." In this concept, university-based R&D is commercialized when students at the university involved in BMDO-funded research graduate and apply their knowledge in the private sector.

BMDO recognizes that by finding dual uses—or better yet, multiple uses—for BMDO-funded R&D (especially at the large-scale systems level), U.S. taxpayers, industries, and the nation as a whole can be vastly rewarded.

Moon-Mapping Mission Also Proves BMDO Technology

Using the latest in military sensors, the Clementine space probe was able to demonstrate BMDO technologies to market areas where poorly performing technologies result in multimillion-dollar mistakes.

Fulfilling dual-use space and defense objectives, the Clementine space probe provided new lunar data while testing the performance and endurance of BMDO technology in the harsh environment of space. This moon-mapping technology-testing mission is a joint effort with participation from BMDO, the National Aeronautics and Space Administration, the Naval Research Laboratory (Washington, DC), and Lawrence Livermore National Laboratory (Livermore, CA).

Although the moon has been extensively studied, Clementine is the first mission to map the entire lunar surface using cameras that produce digital images. Its six onboard sensors enabled scientists to assemble multispectral images of the surface, allowing accurate analysis of the moon's mineral content and geological forces.

Technology used for the Clementine mission has also been adapted for commercial users. The proven prowess of BMDO technologies

has made a positive impression on commercial satellite producers, who are now planning to incorporate Clementine-tested technology into their designs. The satellite industry tends to shy away from untried equipment because poorly performing technologies can result in multimillion-dollar setbacks. However, since all the new technologies have worked on the space probe, they are attracting interest from this skeptical industry.

As discussed in various sections of this publication, some of the technologies being commercialized from the Clementine mission are

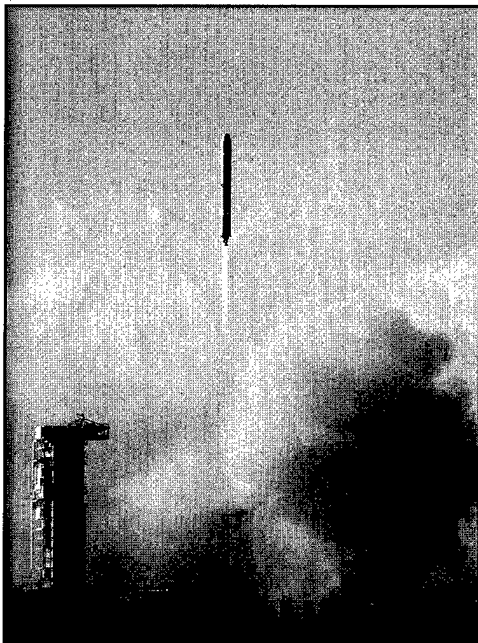
nickel hydrogen batteries produced by Eagle Picher Industries (Butler, WI); inertial measurement units developed by Honeywell (Clearwater, FL); and expert system software developed by Interface and Control Systems (Melbourne, FL).

The value of dual-use advanced technology was demonstrated early in Clementine's mission, when a BMDO-funded battery was able to save the mission. In what could have ended the mission, a software programming error turned Clementine's solar arrays away from their energy source (the sun). The onboard batteries, which needed solar generated electricity to maintain their charge, discharged almost completely to below 20 percent of their rated charge. Typical space-qualified batteries would have permanently failed, unable to recharge even if solar power was restored. However, Clementine used a nickel-hydrogen single pressure vessel battery—the first of its kind for a space system in this application. When mission managers regained control of the spacecraft and properly oriented its solar panels, the batteries again were fully charged, allowing the mission to continue.

Another important aspect of the mission was the efficiency proved by its systems integration. The innovative management of Clementine, combined with the mission's relatively small scale, kept the probe's development within a \$75 million budget and a 22-month schedule. Design of the 500-pound spacecraft began in early 1992, after Department of Defense officials assigned its development to BMDO's Sensor Integration Program, which received assistance from the Naval Research Laboratory and Lawrence Livermore National Laboratory.

The \$75 million for the mission did not permit the typical mission control center, replete with rows and rows of gleaming consoles. Instead, the control team moved into a former garage and warehouse previously used to overhaul trucks. They brought just enough equipment in portable trailers to monitor and control the most important parts of the mission.

continued on page 89



■ Clementine began its mission after a refurbished Titan IIG carried it into earth orbit on January 25, 1994.

Clementine has successfully extended technology over boundaries between government agencies and beyond to commercial markets.

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For the data output, Clementine's managers placed thousands of pictures received from Clementine's sensors on the Internet, where they were instantly available to almost anyone who had an Internet account. This direct access to the historic images was so popular that the Internet "gateway" bogged down regularly as thousands of scientists, engineers, and interested spectators all tried to look at the mission pictures at the same time.

ABOUT THE TECHNOLOGY

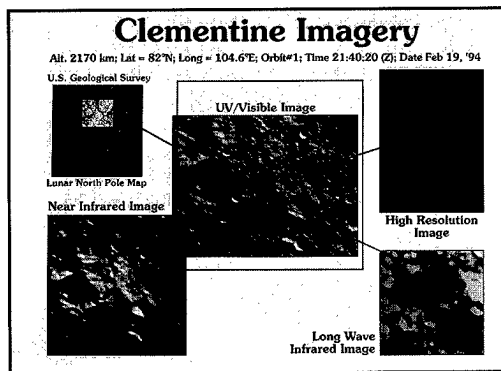
Clementine began its mission after a refurbished Titan IIG carried it into earth orbit on January 25, 1994. After testing its components, ground controllers fired a booster rocket that sent the

space probe to map the moon. Clementine arrived at the moon on February 19, and its lunar mapping mission ended successfully on May 3.

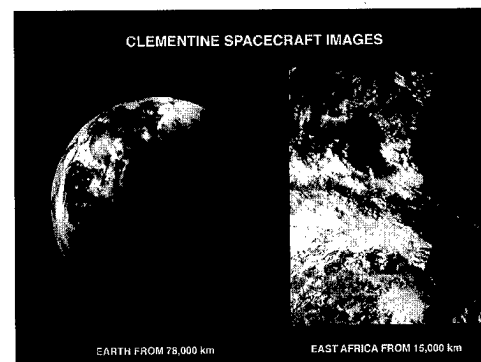
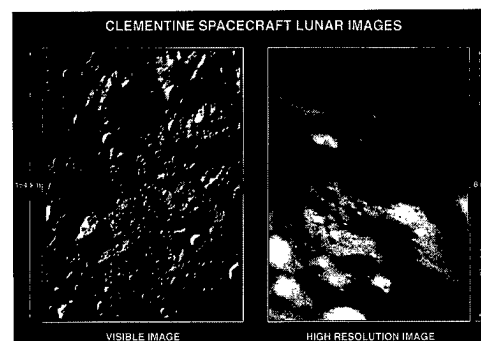
In over 300 orbits of the moon, Clementine recorded more than 1.6 million images, using ultraviolet, infrared, and visible-light cameras. The mission provided the first "whole moon" set of digital

images of the earth's nearest neighbor. The multispectral Clementine images cover 11 color bands and provide unprecedented detail, revealing areas, such as the lunar poles, never before seen in detail. Bistatic radar images generated by Clementine are being closely analyzed for indications of water on the moon, which may lie in deep lunar polar craters that never see sunlight. (Clementine transmitted radar energy toward the moon that was read by earth-based radar receivers.) Before leaving lunar orbit, Clementine also performed a totally autonomous moon-mapping sequence in which its onboard systems made decisions on navigation, sequencing, sensor use, and other mission activities based on rules stored in its mission computer rather than on discrete earth-transmitted commands that conventional missions use.

After the probe left the moon, an onboard problem curtailed its next mission objective, a rendezvous with the asteroid Geographos. The failure, ironically, was in the space-qualified housekeeping computer system, not in one of the 25 new technologies that made up this test. Clementine II is already well into the planning cycle. It has received enthusiastic support from Congress and the defense and scientific communities, who now recognize that military hardware can be successfully used for many other missions.



■ Pictured above and to the right are a few of the thousands of images—in a variety of wavelengths from ultraviolet to infrared—taken by the Clementine spacecraft. Clementine completed the first full-moon mapping, and the images were available on the Internet as soon as they were received.



Delta Clipper Demonstrates A Reusable Single-Stage Rocket

The Delta Clipper Experiment, a reusable single-stage rocket, has already shown that innovative "fly-before-buy" research and development can be applied to a space launcher program.



■ DC-X lifts off for a test flight at White Sands Missile Range on August 18, 1993.

In a program called the Delta Clipper Experiment (DC-X), BMDO recently funded an advanced concept, known as the single-stage-to-orbit vehicle, for launching payloads into space. This program was intended to demonstrate the practicability, reliability, operability, and cost-efficiency of a fully reusable, rapid-turnaround single-stage rocket. The ultimate goal of aircraft-like operations was to develop a reusable launch vehicle for placing components of the Strategic Defense System's space-based segment into orbit. It was also designed to test BMDO systems and components in suborbital flights.

Focused on using existing technologies, the DC-X program has already shown that innovative "fly-before-buy" research and development can be applied to a program for launching rockets into space. Technology transfer in the program has been in the best tradition of dual use, with existing commercial and military technologies being "spun on" to make the demonstration vehicle. If the concept is proved and used in the future, then new enabling technologies will maintain U.S. leadership in space launch systems for both military and civilian uses. The system will also allow for cheap, effective, and reliable access to the next frontier.

The prime contractor for the demonstration program is McDonnell Douglas Aerospace. Roughly \$60 million was needed to design, fabricate, and flight-test the single-stage rocket demonstration vehicle. Using only a small team of contractors, the program delivered the flight vehicle in just 2 years.

In the initial proof-of-concept test, completed in late 1993, a subscale test vehicle successfully completed three short flights at the White Sands Missile Range in New Mexico. These flights proved that the vehicle could be launched, rise a few hundred feet, travel across the ground for a few hundred feet, and then land tail-first using the same engines that launched the vehicle. The program moved to the Department of Defense's Advanced Research Projects Agency (ARPA).

Although the National Aeronautics and Space Administration has expressed some interest in continuing with the concept, the program cur-

rently remains in DOD. In early May 1994, ARPA identified some additional money for three to five additional flights, through approximately the end of August 1994. These tests include a demonstration of a 3-day servicing turnaround between flights, as well as the first in-flight demonstration that the vehicle can rotate from a reentry attitude (nose pointed at the ground) to the tail-first attitude needed to land. NASA's Marshall Space Flight Center will monitor these tests to prepare for the program's continuance, if funding is provided. The first of these additional flights successfully occurred on June 20, 1994.

ABOUT THE TECHNOLOGY

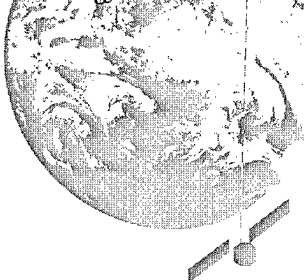
The program uses existing technologies to build both orbital and suborbital reusable launch vehicles that can be launched, recovered, serviced, and quickly relaunched with a minimum of resources. The first test vehicle weighs 20,000 pounds, stands 40 feet tall, and has a conical shape, with a base diameter of 13 1/3 feet. It is about one-third the size needed for a fully operational system. It uses four modified RL-10A5 rocket engines generating 13,500 pounds of thrust. Modifications to the long-used RL-10 design permit the extensive throttling that enables the vehicle to be launched and then return to a landing site, hover, and land tail first after a mission.

The guidance system on the proof-of-concept vehicle uses a 32-bit F-15 aircraft guidance system with ring laser gyros. An accelerometer and rate gyro package is used from an F/A-18 aircraft. A Global Positioning System receiver, digital telemetry package, and radar altimeter complete the instrumentation, navigation, and control package. Although borrowed from other programs, these technologies are adequate for the first phase of this program.

A modified version of the DC-X, called the DC-XA, will act as a test bed for other advanced launch technologies. Among these are a graphite-epoxy liquid hydrogen tank and a Russian-made aluminum-lithium oxygen tank for the cryogenic propellants and a graphite-epoxy interstage structure.

Lasers Answer Call For Communications

As a dual-use technology, ThermoTrex Corporation's LaserCom could transmit information between satellites for television, telephones, and computer networks faster and more accurately than current technology.



The international community relies heavily on satellites for worldwide telecommunications, using radio-frequency (RF) waves to transmit information. But such systems could be vastly improved if they transmitted information between satellites using laser technology instead of RF waves. They could be smaller, faster, and more accurate.

ThermoTrex Corporation (San Diego, CA) has answered this call with LaserCom, the next-generation laser-based system. LaserCom optically receives and broadcasts data with lasers. Its main advantage is for high-speed communications between fast-moving platforms such as small, low-earth orbit or high-altitude platforms.

LaserCom is expected to perform better than RF satellite communications because data can be transmitted faster. It can move up to 1 billion bits of data per second, while conventional RF systems have a data rate of only 20 million bits per second. The system is also more resistant to jamming and data interception.

LaserCom's small size and light weight can reduce launch costs and allow for smaller satellites. While LaserCom uses a small 0.1-meter telescope for detection and transmission, the RF communications system uses a dish about 3 meters in diameter. In addition, LaserCom needs less power than conventional radio-wave satellite communication systems. Transmission power in the 1-gigabit-per-second LaserCom

system is 400 milliwatts at peak, compared with a peak of 150 watts for a conventional 20-megabit-per-second RF system.

The BMDO IS&T program is funding LaserCom for ballistic missile defense (the Air

Force has also funded this project). However, this system could be used for other government and commercial satellite communications programs as well. And in the near term, tactical military aircraft can use this system to exchange data with airborne surveillance platforms.

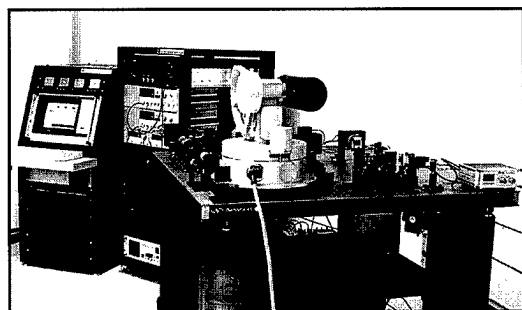
ThermoTrex is also finding other uses for the individual components of the system. For example, a research program with the U.S. Army is using atomic line filters (see below) to locate the plumes created by rotors of terrain-masked helicopters. And the National Aeronautics and Space Administration has procured laser gimbal-mount drives designed by ThermoTrex for future laser-based space communications systems.

ABOUT THE TECHNOLOGY

To transmit data in a LaserCom satellite system, an earth-based station first sends information to the closest overhead satellite. This satellite then relays the information via a laser beam with a wavelength of 810 nanometers to the transceivers of intermediate satellites. Laser beacons are used to ensure that intermediate satellites can quickly and precisely track "next-in-line" or receiving satellites in the system. Information is then sent to the satellite receiving the information. Because the earth's atmosphere distorts laser signals, radio waves would still be used to send the information to and from the ground. For all-weather operations, however, as few as five ground stations would permit communications over 99 percent of the time.

ThermoTrex has demonstrated a 20-transceiver laser communications network in the laboratory. Key components include the atomic line filter and a highly precise tracking gimbal. The atomic line filter alleviates problems caused by reflected sunlight, which can interfere with laser beacon detection. This component is attached to the transceiver between the receiver and the tracking charge-coupled device (CCD) camera, excluding all light except the extremely narrow bandwidth (30 megahertz) of the laser beacon.

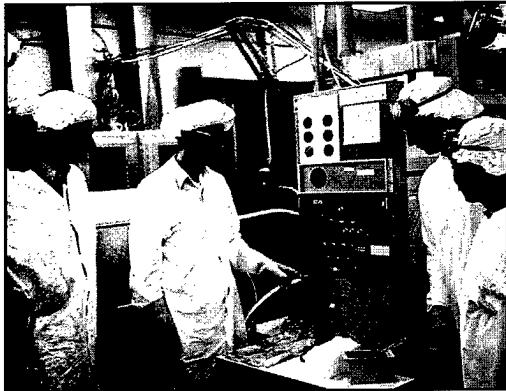
To provide a high precision tracking gimbal for the system in the testbed demonstration, ThermoTrex also incorporated the RotoLok® Rotary Drive developed by Sagebrush Technology (Albuquerque, NM). This BMDO-supported technology has been widely commercialized, as described in the 1992 *Technology Applications Report*.



■ ThermoTrex has demonstrated a 20-transceiver laser communications network in the laboratory. Pictured above is a complete node transceiver system.

Technology Transfers From Graduate Students To Industry

One recent Ph.D. recipient is applying the knowledge gained in BMDO-funded projects at Lehigh University to develop a product line that measures pressure and monitors temperature in nuclear reactors.



■ Students at Lehigh University have gained hands-on experience in microelectronics R&D—skills they can later transfer to the commercial sector.

In most of the articles in this report, technology has been transferred in such a way that a device or system—something tangible—for ballistic missile defense has been applied to a medical, environmental, or other commercial use. But there is another kind of technology transfer, called intellectual technology transfer, where knowledge transitions from one application to another, embodying the concept of dual use. You can't touch it; you can't see it; but it's having a positive impact on the nation's economy.

In intellectual technology transfer, technology is transferred through the student-to-professional transition. In many cases, students who have learned through government-sponsored graduate programs apply what they learned when they become professionals, often in the commercial sector. Through intellectual technology transfer, students' skills and experiences acquired in these programs have led to developments that may not only provide the United States with matchless defense capabilities but

also may improve the nation's economic competitiveness.

For example, in a BMDO-funded program at Lehigh University (Bethlehem, PA), graduate students are conducting research and development to replace magnetic hard drives with nonvolatile semiconductor memory. This memory can then be used in radiation-hardened computers in space applications.

The students sponsored by the program have gained valuable theoretical and experimental knowledge through this research and have taken it with them to their private sector jobs.

Students who learned about ballistic missile defense are now impacting big business. Graduates in this BMDO-funded program at Lehigh are now applying the knowledge gained in the program to many major corporations throughout the United States, where they now work, according to Dr. Marvin White, Sherman Fairchild Professor of solid-state studies, electrical engineering, and computer

science. Such corporations include IBM, AT&T, Intel, Motorola, and Texas Instruments.

In some cases, intellectual technology transfer has led to job creation. One recent Ph.D. recipient is at Westinghouse in Pittsburgh, using the expertise gained at Lehigh to develop a product line that measures pressure and monitors temperature in nuclear reactors. From the work of this former student springs an entire infrastructure, as the company employs people to manufacture, test, and develop the line.

Lehigh's intellectual technology transfer can make key contributions to the U.S. economy. Students conducting BMDO research often take jobs in the microelectronics and semiconductor areas, two growing industries in which, not coincidentally, the United States is excelling. Now the world leader, the nation recently regained strength over Japan in semiconductor sales and production. This is partly due to the United States' superiority in microprocessors. It is also due to the nation's demand for lower power-consumption, which, in many applications, continues to drive microminiaturization. Dr. White's students leave Lehigh with first-hand experience in these areas.

The educational program also works toward scientific leadership. Dr. White is enthusiastic about the process, claiming that "through programs like these, we are educating the next generation of scientists and engineers to make industry more competitive."

Commercialization

Is A Continuous

Process

From concept to commercialization, it took 82 years to bring the fluorescent light to market.

Throughout history, the evolution of product commercialization has been a long-term process; the progress of some of the most important, now taken for granted advances has spanned over decades before products were fully developed and widely available. For example, from concept to commercialization, it took 82 years to bring the fluorescent light to market. Likewise, commercialization stories in this report have not ended. In fact, by looking at the new developments of companies since they were mentioned in the 1993 edition of the *Technology Applications Report*, you can see the dynamics of the market for defense-developed technology in the commercial marketplace. Here are just a few examples:

■ **Reveo revs up new product line through VRex.** Byte magazine recently said "good show" to VRex (Hawthorne, NY) for its 3-dimensional stereoscopy notebook computer called CyberBook™. After the product was introduced at the November '93 COMDEX show in Las Vegas, NV, Byte gave it the "best of COMDEX '93" award. Behind the scenes is really Reveo (same location), which spun out VRex in 1993 to develop and manufacture its 3-dimensional imaging techniques. Starting at \$3,500, CyberBook™ also comes with SMUX™ software so that users can create 3-dimensional stereoscopic images and display them on the CyberBook™. The software prices range from \$300 to \$400.

■ **Racing ahead to commercialize BMDO-funded research.** Unveiled in January 1994, the Patriot prototype race car showed a low-emissions, high-energy-efficiency profile at the North American International Auto Show. This prototype is part of the collaborative efforts of the Chrysler Corporation and SatCon (Cambridge, MA)—a company that is applying its R&D (partially funded by BMDO) in active motion control. Chrysler has announced plans to enter the Patriot in select endurance races beginning in 1995. The team's new developments are expected to proclaim the message: cars that emit less pollution and use less gasoline per mile can still be fun to drive. In another deal with a major North American automotive manufacturer, SatCon is developing advanced power steering components for better handling and fuel economy. Vehicles with this component should be available in the mid- to late 1990s.

■ **Leader in diamond coatings enters ventures.** SI Diamond (Houston, TX), with its Amorphous Diamond™ coating process, has entered into a long list of ventures that may make diamond cold cathode flat-panel displays a given for portable computers and advanced home entertainment systems. As a key element for scaling up its coating process, the company has acquired Plasmatron Coatings and Systems, Inc., (Cinnaminson, NJ)—a designer and builder of coating and vacuum systems.

SI Diamond also has an agreement with Fischer Imaging Corporation (Denver, CO) to codevelop a flat-panel display system for digital mammography. And teaming with no less than the laboratory that pioneered color TV, the David Sarnoff Research Center, researchers are perfecting color phosphors and screens for flat-panel displays. In addition, in a cooperative research and development agreement (CRADA), SI Diamond has teamed with Commonwealth Scientific (Alexandria, VA) and Lawrence Livermore National Laboratory (Livermore, CA) to develop novel, advanced hard coatings.

■ **Science Research Associates and Ciencia target the environment.** Science Research Associates, or SRA, (Glastonbury, CT) and Ciencia, Inc., (East Hartford, CT) are now focusing on ways to help industries monitor pollution emissions. SRA is adapting its BMDO-funded technology to develop a sensor that can monitor smokestack gases. The sensor will allow rapid, real-time measurements with high sensitivity. It is also expected to be rugged and portable and may be able to monitor several pollutants without requiring engineers to change the physical instrumentation. In addition, Ciencia has recently developed a remote-sensing hyperspectral imager for pollution monitoring. Both companies' work is based on acousto-optic tunable filters (AOTFs)—devices that use ultrasound to control the phase, amplitude, frequency, and angular direction of laser beams.



*Amber,
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The Technology Applications program looks forward to the continued success of these and other BMDO-funded companies, laboratories, and universities in providing innovative products that will help maintain the United States' leadership in the international economic arena.

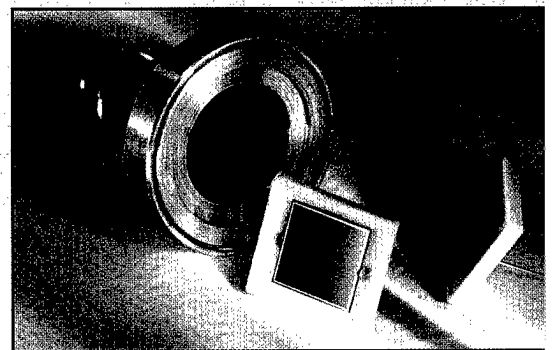
If you are looking for more information on innovative technologies or the Technology Applications program, you can write, call, fax, or e-mail us at:

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Technology
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TECHNOLOGY APPLICATIONS



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